

SECTION 5.0

EMISSIONS OF ARSENIC AND ARSENIC COMPOUNDS FROM THE METALLURGICAL INDUSTRY

5.1 Primary Lead Smelting

Lead is recovered from a sulfide ore, primarily galena (lead sulfide [PbS]), which also contains small amounts of copper, iron, zinc, and other trace elements. Arsenic typically appears in the form of arsenopyrite (FeAsS) or arsenic sulfide (As₂S₃) in lead-bearing ore. A description of the process used to manufacture lead and a discussion of the emissions resulting from the various operations are presented below.

A list of primary lead smelters currently in operation within the United States is given in Table 5-1. Primary lead smelters produced 449,800 tons of refined lead in 1990.¹

5.1.1 Process Description

Figure 5-1 presents a typical process flow diagram for primary lead smelting. The recovery of lead from the lead ore consists of three main steps: sintering, reduction, and refining.²

Sintering is carried out in a sintering machine, which is a continuous steel pallet conveyor belt. Each pallet consists of perforated grates, and beneath the grates are wind boxes, which are connected to fans to provide a draft through the moving sinter charge. Depending on the direction of the draft, the sinter machine is characterized as either an updraft or downdraft

TABLE 5-1. DOMESTIC PRIMARY LEAD SMELTERS AND REFINERIES

Smelter	Refinery	1990 Production tons
ASARCO, East Helena, MT	ASARCO, Omaha, NE ^a	72,500
ASARCO, Glover, MO	Same site	123,200
Doe Run (formerly St. Joe), Herculaneum, MO	Same site	254,100

Source: Reference 1.

^a Scheduled to be closed.

machine. Except for the draft direction, all machines are similar in design, construction, and operation. Capacities range from 1,000 to 2,500 tons per day. Lead concentrates account for 30 to 35 percent of the input material for the sintering process. The balance of the charge consists of fluxes such as limestone and large amounts of recycled sinter or smelter residues.³

The blast furnace reduces the lead oxide produced in the sintering machine to elemental lead and removes undesirable impurities as a slag. Reduction reactions to elemental lead occur around 2,900°F. The resulting metal, called bullion, assays 94 to 98 percent lead. The furnace is a rectangular, water-cooled steel shell or shaft atop a refractory lined crucible or hearth. Both sides are equipped with tuyeres through which pressurized combustion or blast air is introduced. Furnace capacities range from 500 to 1,000 tons per day. The charge to the furnace includes sinter, coke, slags from drossing and refining processes, silica, limestone, and baghouse dust. About 80 percent of the charge consists of sinter that may contain from 28 to 50 percent lead. Blast air is introduced through the side-mounted tuyeres resulting in partial combustion of coke and formation of carbon monoxide and providing the heat required to reduce lead oxide to lead bullion. Most of the impurities react with the silica and limestone and form a slag. The slag is skimmed continuously from the furnace and is treated either at the smelter or is shipped elsewhere to recover the metal content. Slags that are high in zinc are generally treated at the smelter in a zinc forming furnace to recover zinc oxide.³

Source: Reference 2.

The lead bullion is tapped from the furnace periodically, and is usually treated in a drossing kettle before undergoing final refining. In the kettle, the bullion is cooled and the higher melting impurities, primarily copper, float to the surface and form a dross which is skimmed off and subsequently treated in a reverberatory furnace. The bullion undergoes a final refining in a series of cast iron kettles. The final lead product, typically 99.99 percent or more pure, is then cast into pigs or ingots for shipping.³

The function of the dross reverberatory furnace is to separate lead bullion carried over in the dross from other metals of economic value or contaminants in the dross. The dross lead content may be as high as 90 percent. Although much smaller, the reverberatory furnace used is similar in construction to the reverberatory furnace used in copper smelting. Where applied, end-products usually include lead bullion, which is recycled, matte, which is rich in copper and usually sent to a copper smelter for copper recovery, and speiss, which is high in arsenic and antimony.³

5.1.2 Emission Control Techniques

Emission controls on primary lead smelter operations are used for controlling particulate matter (PM) and sulfur dioxide (SO₂) emissions resulting from the blast furnace and sintering machines. Centrifugal collectors (cyclones) may be used in conjunction with fabric filters or electrostatic precipitators (ESPs) for PM control. In addition, fugitive emissions from the drossing kettles are typically controlled by building enclosure or kettle hooding systems.³ There were no arsenic removal efficiency tests available to determine the exact removal efficiencies of the typical control devices used at primary lead smelting facilities. However, it has been estimated by analogy to copper smelting data, that arsenic removal efficiencies greater than 90 percent can be achieved by fabric filter systems and that the “best available” ventilation capture systems used to control fugitive emissions are capable of approximately 90 percent fugitive emission control.³

5.1.3 Emissions

Most of the arsenic entering with the plant feed (>80 percent) can be accounted for in the solid products leaving a facility.⁴ Arsenic can potentially be emitted from each unit operation within a primary lead smelting facility. Arsenic removal from the lead-bearing portion of the charge material includes volatilization, slagging, and an association with the matte and speiss phases (mixture of impure metallic arsenides) that are ultimately shipped to copper smelters. Typically, arsenic will be emitted as PM. If any particle size partitioning occurs, it is generally found that arsenic is most likely to be associated with the finer particles.⁴

In addition, for processes where the operating temperature is near the boiling point of arsenic, arsenic fumes may be emitted. For example, arsenic can be volatilized as arsenic trioxide from sinter plants, blast furnaces, dross reverberatory furnaces, zinc fuming furnaces, and reverberatory softening furnaces (lead refining).⁴ One study from a Missouri lead smelter determined that approximately 12.9 percent of the arsenic entering a smelter was unaccounted for in the solid waste and product streams. The study concluded that this figure represented the approximate amount that was emitted to the atmosphere.⁴ Table 5-2 presents an arsenic emission factor that may be used for estimating arsenic emissions from an entire primary lead smelting operation.⁴ The reader is cautioned that this emission factor represents a rough estimate only and the quality of the factor is uncertain.

5.2 Secondary Lead Smelting

5.2.1 Process Description

The secondary lead smelting industry produces elemental lead and lead alloys by reclaiming lead, mainly from scrap automobile batteries. Blast, reverberatory, rotary, and electric furnaces are used for smelting scrap lead and producing secondary lead. Smelting is the

TABLE 5-2. ARSENIC EMISSION FACTOR FOR PRIMARY LEAD SMELTING FACILITIES

SCC	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Range in lb/ton ^a	Emission Factor Rating
3-03-010	Entire process	Fabric Filter	1.94×10^{-1}	2.80×10^{-2} - 5.80×10^{-1}	U

Source: Reference 4.

^a Emission factor is expressed in lb of pollutant emitted per ton of lead produced. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

reduction of lead compounds to elemental lead in a high-temperature furnace, which requires higher temperatures (2,200 to 2,300°F) than those required for melting elemental lead (621 °F). Secondary lead may be refined to produce soft lead (which is nearly pure lead) or alloyed to produce hard lead. Most of the lead produced by secondary lead smelters is used in the production of lead-acid batteries.⁵

Lead-acid batteries represent about 90 percent of the raw materials at a typical secondary lead smelter, although this percentage may vary from one plant to the next. These batteries contain approximately 18 lb of lead per battery consisting of 40 percent lead alloys and 60 percent lead oxide. Other types of lead-bearing raw materials recycled by secondary lead smelters include drosses (lead-containing byproducts of lead refining), which may be purchased from companies that perform lead alloying or refining but not smelting; battery plant scrap, such as defective grids or paste; and scrap lead, such as old pipes or roof flashing. Other scrap lead sources include cable sheathing, solder, and babbitt-metal.⁵

As illustrated in Figure 5-2, the normal sequence of operations in a secondary lead smelter is scrap receiving, charge preparation, furnace smelting, and lead refining, alloying, and casting.⁵ In the majority of plants, scrap batteries are first sawed or broken open to remove the lead alloy plates and lead oxide paste material. The removal of battery covers is typically accomplished using an automatic battery feed conveyor system and a slow-speed saw. Hammer mills or other crushing/shredding devices are then used to break open the battery cases. Float/sink separation systems are typically used to separate plastic battery parts, lead terminals, lead oxide paste, and rubber parts. The majority of lead smelters recover the crushed plastic materials for recycling. Rubber casings are usually landfilled or incinerated in the smelting furnace for their fuel value, and in many cases, lead is reclaimed from the castings.

Paste desulfurization, an optional lead recovery step used by some secondary lead smelters, requires the separation of lead sulfate and lead oxide paste from the lead grid metal, polypropylene plastic cases, separators, and hard rubber battery cases. Paste desulfurization

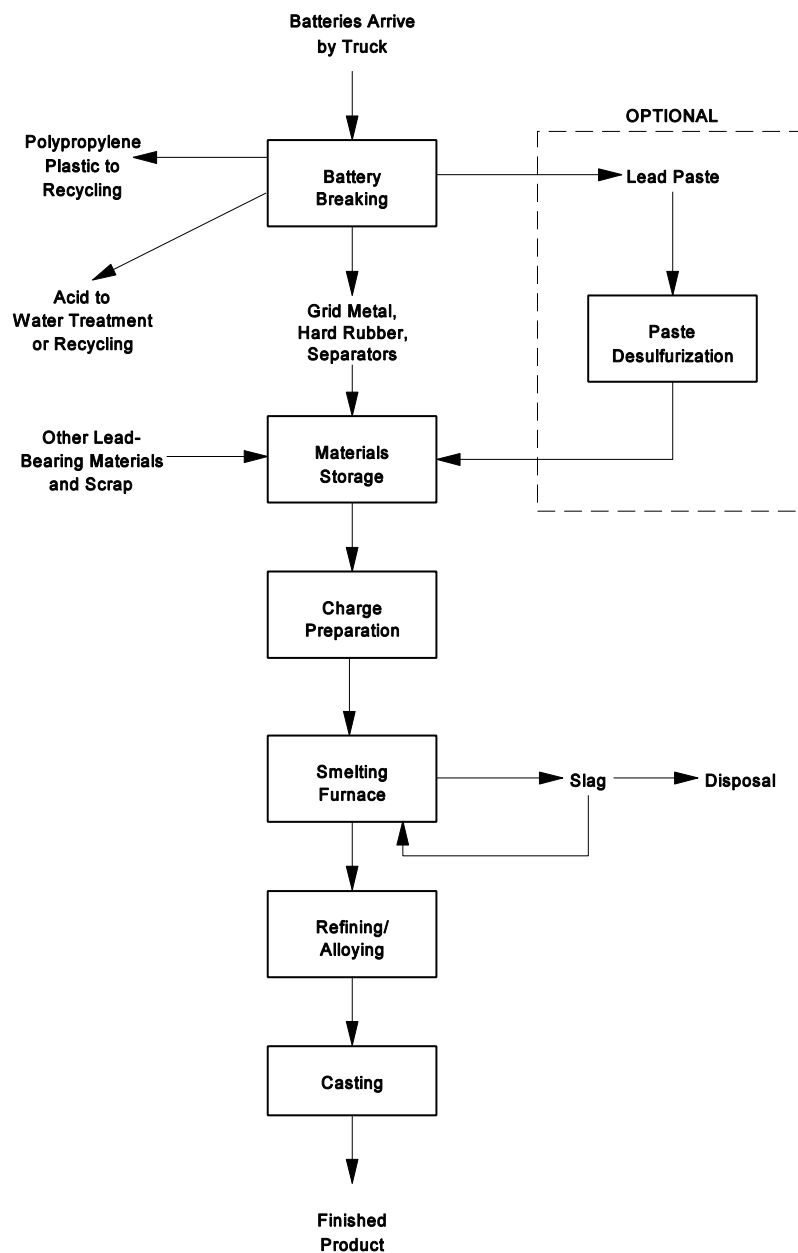


Figure 5-2. Simplified Process Flow Diagram for Secondary Lead Smelting

Source: Reference 5.

involves the chemical removal of sulfur from the lead battery paste. The process improves furnace efficiency by reducing the need for fluxing agents to reduce lead-sulfur compounds to lead metal. The process also reduces SO₂ furnace emissions. However, SO₂ emissions reduction is usually a less important consideration because many plants that perform paste desulfurization are also equipped with SO₂ scrubbers. About one-half of smelters perform paste desulfurization.⁵

After removing the lead components from the batteries, the lead scrap is combined with other charge materials such as refining drosses and flue dust which are charged to a reverberating furnace. Reverberating furnace slag, coke, limestone, sand, and scrap iron are fed to a blast, rotary or electric smelting furnace. Smelting furnaces are used to produce crude lead bullion, which is refined and/or alloyed into final lead products. In 1994 there were approximately 14 reverberatory furnaces, 24 blast furnaces, 5 rotary furnaces, and 1 electric furnace operating in the secondary lead industry in the United States.⁵ Blast and reverberatory furnaces are currently the most common types of smelting furnaces used in the industry, although some new plants are using rotary furnaces.

Reverberatory Furnaces

A reverberatory furnace (Figure 5-3) is a rectangular refractory-lined furnace operated on a continuous basis.⁵ Natural gas- or fuel oil-fired jets located at one end or at the sides of the furnace are used to heat the furnace and charge material to an operating temperature of about 2,200 to 2,300°F.⁵ Oxygen enrichment may be used to decrease the combustion air requirements. Reverberatory furnaces are maintained at negative pressure by an induced draft fan.

Reverberatory furnace charge materials include battery grids and paste, battery plant scrap, rerun reverberatory furnace slag, flue dust, drosses, iron, silica, and coke. A typical charge over one hour may include 9.3 tons of grids and paste to produce 6.2 tons of lead.⁵

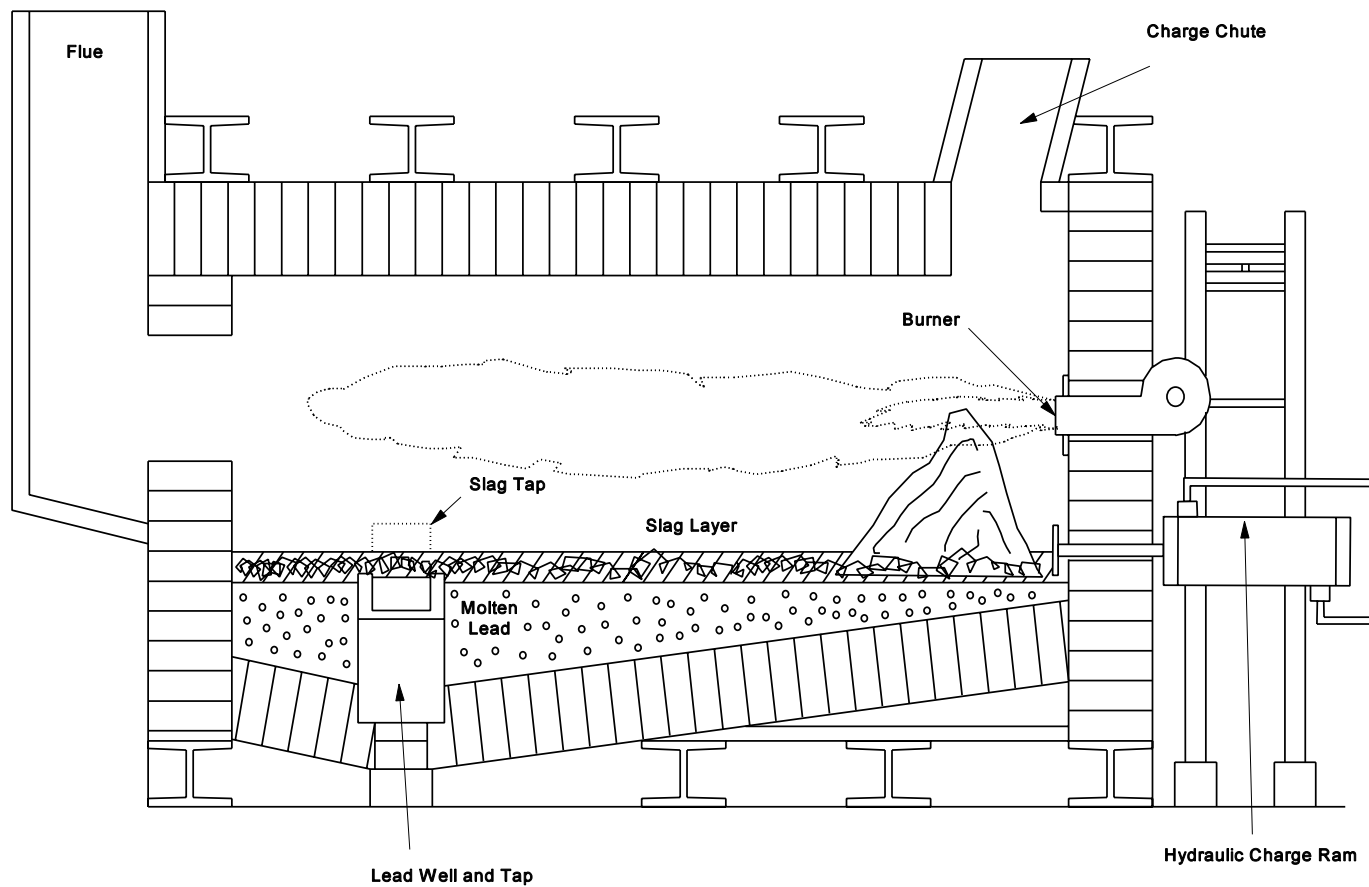
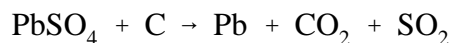


Figure 5-3. Cross-Sectional View of a Typical Stationary Reverberatory Furnace

Source: Reference 5.

Charge materials are often fed to a natural gas- or oil-fired rotary drying kiln, which dries the material before it reaches the furnace. The temperature of the drying kiln is about 400°F, and the drying kiln exhaust is drawn directly into the reverberatory furnace or ventilated to a control device. From the rotary drying kiln, the feed is either dropped into the top of the furnace through a charging chute, or fed into the furnace at fixed intervals with a hydraulic ram. In furnaces that use a feed chute, a hydraulic ram is often used as a stoker to move the material down the furnace.

Reverberatory furnaces are used to produce a soft, nearly pure lead product and a lead-bearing slag. This is done by controlling the reducing conditions in the furnace so that lead components are reduced to metallic lead bullion while the alloying elements (antimony, tin, arsenic) in the battery grids, posts, straps, and connectors are oxidized and removed in the slag. The reduction of PbSO_4 and PbO is promoted by the carbon-containing coke added to the charge material:



The PbSO_4 and PbO also react with the alloying elements to form lead bullion and oxides of the alloying elements, which are removed in the slag.

The molten lead collects in a pool at the lowest part of the hearth. Slag collects in a layer on top of this pool and retards further oxidation of the lead. The slag is made up of molten fluxing agents such as iron, silica, and lime, and typically has significant quantities of lead. Slag is usually tapped continuously and lead is tapped intermittently. The slag is tapped into a mold. The slag tap and mold are hooded and vented to a control device. Reverberatory furnace slag usually has a high lead content (as much as 70 percent by weight) and is used as feed material in a blast or electric furnace to recover the lead. Reverberatory furnace slag may also be rerun through the reverberatory furnace during special slag campaigns before being sent to a blast or electric furnace. Lead may be tapped into a mold or directly into a holding kettle. The lead tap is usually hooded and vented to a control device.⁵

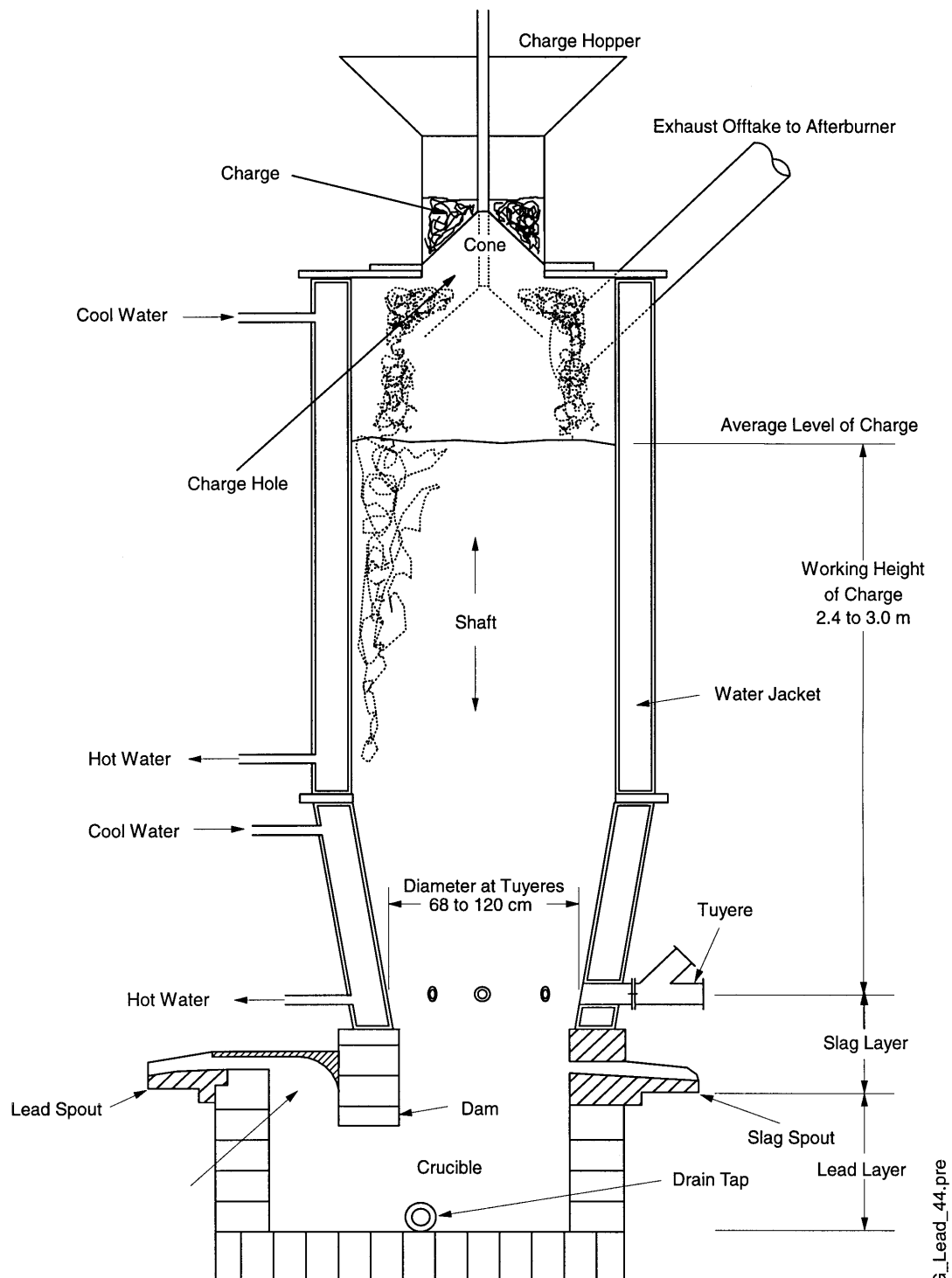
Blast Furnaces

A blast furnace (Figure 5-4) is a vertical furnace that consists of a crucible with a vertical cylinder affixed to the top.⁵ The crucible is refractory-lined and the vertical cylinder consists of a steel water-jacket. Oxygen-enriched combustion air is introduced into the furnace through tuyeres located around the base of the cylinder.

Charge materials are pre-weighed to ensure the proper mixture and then are introduced into the top of the cylinder using a skip hoist, a conveyor, or a front-end loader. The charge fills nearly the entire cylinder. Charge material is added periodically to keep the level of the charge at a consistent working height while lead and slag are tapped from the crucible. Coke is added to the charge as the primary fuel, although natural gas jets may be used to start the combustion process. Combustion is self-sustaining as long as there is sufficient coke in the charge material. Combustion occurs in the layer of the charge nearest the tuyeres.

At plants that operate only blast furnaces, the lead-bearing charge materials may include broken battery components, drosses from the refining kettles, agglomerated flue dust, and lead-bearing slag. A typical charge over one hour may include 4.8 tons of grids and paste, 0.3 tons of coke, 0.1 tons of calcium carbonate, 0.07 tons of silica, 0.5 tons of cast iron, and 0.2 tons of rerun blast furnace slag, to produce 3.7 tons of lead. At plants that also have a reverberatory furnace, the charge materials will also include lead-bearing reverberatory furnace slag.⁵

Blast furnaces are designed and operated to produce a hard (high alloy content) lead product by achieving greater furnace reduction conditions than those typically found in a reverberatory furnace. Fluxing agents include iron, soda ash, limestone, and silica (sand). The oxidation of the iron, limestone, and silica promotes the reduction of lead compounds and prevents oxidation of the lead and other metals. The soda ash enhances the reaction of PbSO_4 and PbO with carbon from the coke to reduce these compounds to lead metal.



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Figure 5-4. Cross-Section of a Typical Blast Furnace

Source: Reference 5.

Lead tapped from a blast furnace has a higher content of alloying metals (up to 25 percent) than lead produced by a reverberatory furnace. In addition, much less of the lead and alloying metals are oxidized and removed in the slag, so the slag has a low metal content (e.g., 1 to 3 percent) and may qualify as a nonhazardous solid waste.

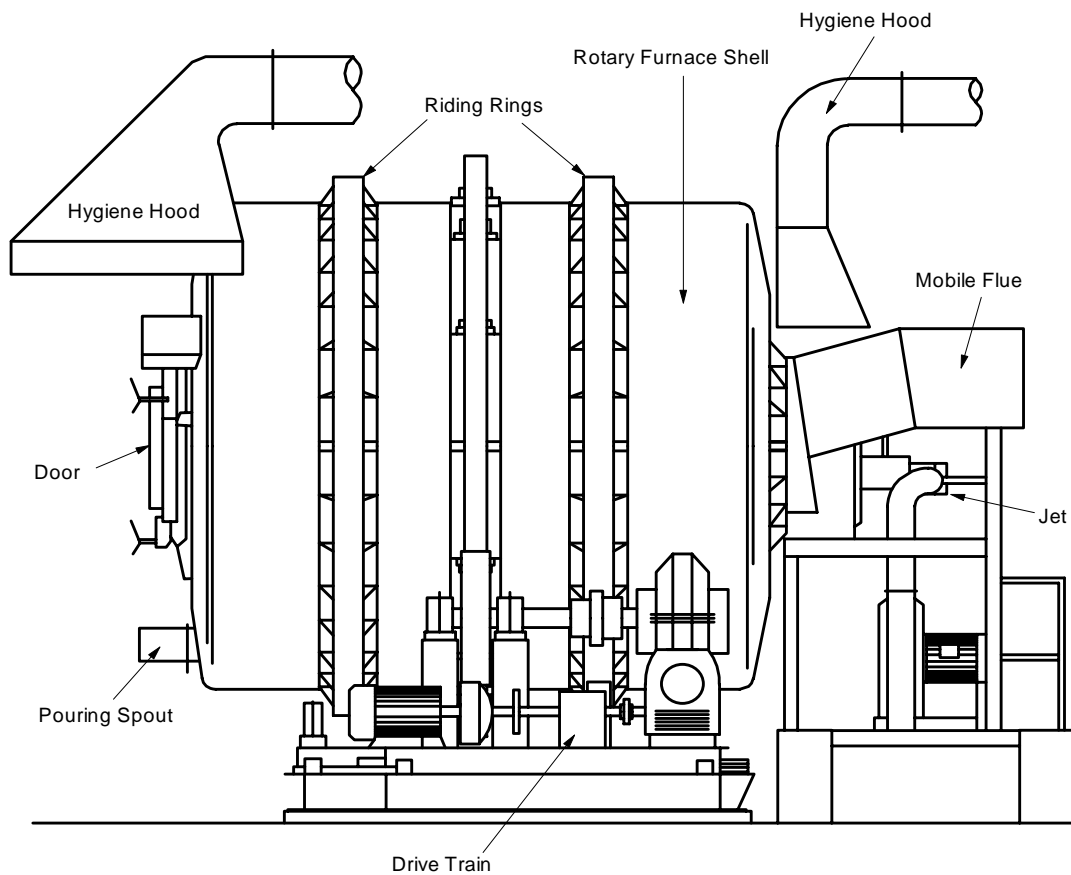
Because air is introduced into the blast furnace at the tuyeres, blast furnaces are operated at positive pressure. The operating temperature at the combustion layer of the charge is between 2,200 and 2,600°F, but the temperature of the gases exiting the top of the charge material is only between 750 and 950°F.

Molten lead collects in the crucible beneath a layer of molten slag. As in a reverberatory furnace, the slag inhibits the further oxidation of the molten metal. Lead is tapped continuously and slag is tapped intermittently, slightly before it reaches the level of the tuyeres. If the tuyeres become blocked with slag, they are manually or automatically “punched” to clear the slag. A sight glass on the tuyeres allows the furnace operator to monitor the slag level and ensure that the tuyeres are clear of slag. At most facilities, the slag tap is temporarily sealed with a clay plug, which is driven out to begin the flow of slag from the tap into a crucible. The slag tap and crucible are enclosed in a hood, which is vented to a control device.

A weir dam and siphon in the furnace are sometimes used to remove the lead from beneath the slag layer. Lead is tapped from a blast furnace into either a crucible or directly to a refining kettle designated as a holding kettle. The lead in the holding kettle is kept molten before being pumped to a refining kettle for refining and alloying. The lead tap on a blast furnace is hooded and vented to a control device.

Rotary Furnaces

As noted above, rotary furnaces (sometimes referred to as rotary reverberatory furnaces) (Figure 5-5) are used at only a few recently constructed secondary lead smelters in the



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Figure 5-5. Side View of a Typical Rotary Reverberatory Furnace

Source: Reference 5.

United States.⁵ Rotary furnaces have two advantages over other furnace types: the ease of adjusting the relative amount of fluxing agents (because the furnaces are operated on a batch rather than a continuous basis), and better mixing of the charge materials.

A rotary furnace consists of a refractory-lined steel drum mounted on rollers with a variable-speed motor to rotate the drum. An oxygen-enriched natural gas or fuel oil jet at one end of the furnace heats the charge material and the refractory lining of the drum. The connection to the flue is located at the same end as the jet. A sliding door at the end of the furnace opposite the jet allows charging of material to the furnace. Charge materials are typically placed in the furnace using a retractable conveyor or charge bucket, although other methods are possible.

Lead-bearing raw materials charged to rotary furnaces include broken battery components, flue dust, and drosses. Rotary furnaces can use the same lead-bearing raw materials as blast furnaces. They usually produce slag that is relatively free of lead, less than 2 percent. A rotary furnace can be used instead of a blast furnace.

Fluxing agents for rotary furnaces may include iron, silica, soda ash, limestone, and coke. The fluxing agents are added to promote the conversion of lead compounds to lead metal. Coke is used as a reducing agent rather than as a primary fuel. A typical charge may consist of 12 tons of wet battery scrap, 0.8 tons of soda ash, 0.6 tons of coke, and 0.6 tons of iron, and will yield approximately 9 tons of lead product.⁵

The lead produced by rotary furnaces is a semi-soft lead with an antimony content somewhere between that of lead from reverberatory and blast furnaces. Lead and slag are tapped from the furnace at the conclusion of the smelting cycle. Each batch takes 5 to 12 hours to process, depending on the size of the furnace. Like reverberatory furnaces, rotary furnaces are operated at a slight negative pressure.

Electric Furnaces

An electric furnace consists of a large, steel, kettle-shaped container that is refractory-lined (Figure 5-6).⁵ A cathode extends downward into the container and an anode is located in the bottom of the container. Second-run reverberatory furnace slag is charged into the top of the furnace. Lead and slag are tapped from the bottom and side of the furnace, respectively. A fume hood covering the top of the furnace is vented to a control device. In an electric furnace, electric current flows from the cathode to the anode through the scrap charge. The electrical resistance of the charge causes the charge to heat up and become molten. There is no combustion process involved in an electric furnace.

There is only one known electric furnace in operation in the U.S. for the secondary lead industry. It is used to process second-run reverberatory furnace slag, and it fulfills the same role as a blast furnace used in conjunction with a reverberatory furnace. However, the electric furnace has two advantages over a blast furnace. First, because there are no combustion gases, ventilation requirements are much lower than for blast or reverberatory furnaces. Second, the electric furnace is extremely reducing, and produces a glass-like, nearly lead-free slag that is nonhazardous.⁵

Refining, the final step in secondary lead production, consists of removing impurities and adding alloying metals to the molten lead obtained from the smelting furnaces to meet a customer's specifications. Refining kettles are used to purify and alloy molten lead.

5.2.2 Emission Control Techniques

Control devices at secondary smelters are primarily aimed at controlling SO₂ and PM emissions. Control devices used to control furnace operation emissions include baghouses and scrubbers. Typically, baghouses are preceded by an afterburner and cooler when applied on a blast furnace and a cooler alone when used on a reverberatory furnace. Scrubbers installed after

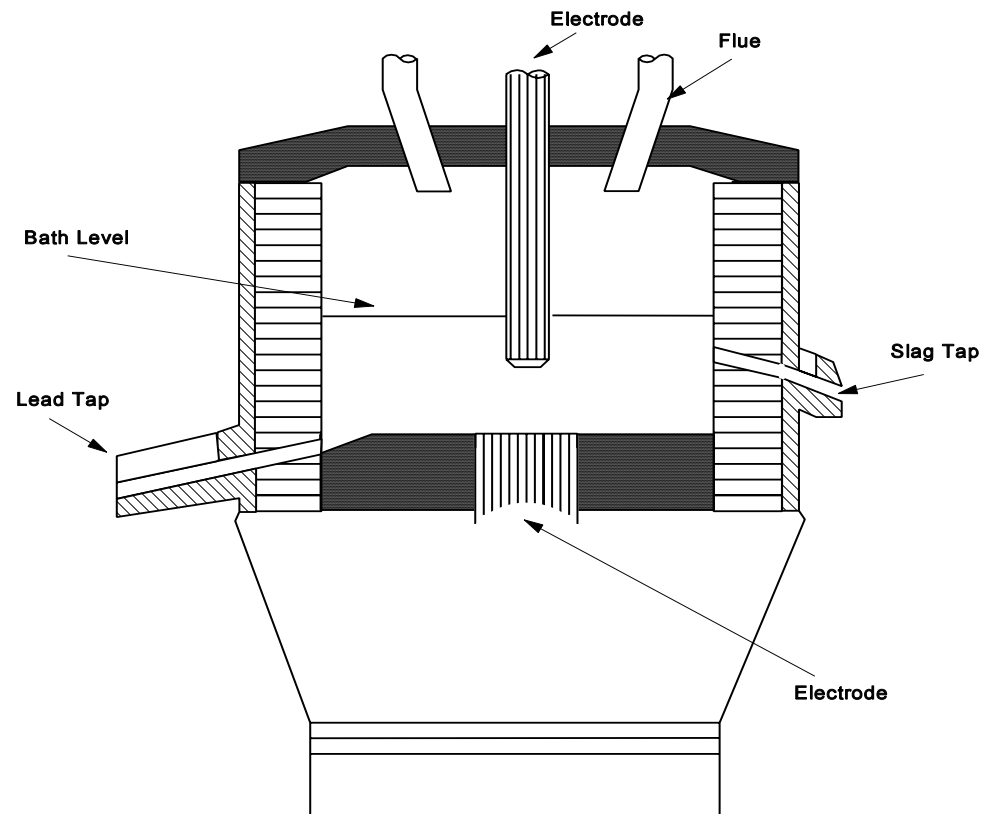


Figure 5-6. Cross-Sectional View of an Electric Furnace for Processing Slag

Source: Reference 5.

baghouses are primarily aimed at controlling SO₂ emissions. Hooding and ventilation to baghouses are commonly used to control process fugitive emissions. Nonprocess fugitive emissions can be controlled by implementing wetting techniques, as well as enclosure of storage piles.

Certain work practices and personal protection strategies can be implemented to reduce worker arsenic exposure. These include housekeeping, administrative controls, and the use of respirators, gloves, goggles, and aprons.⁶

5.2.3 Emissions

In secondary lead smelting operations, arsenic can be emitted in some degree from each process unit. In addition, there can be fugitive arsenic emissions from both process and nonprocess sources. In general, arsenic emissions vary with the amount of arsenic in the feed material, the operating conditions of the furnace, the amount of chlorides in the feed material, and the slag composition. Arsenic emission factors for secondary lead smelting are presented in Table 5-3.^{4,7,8,9}

The primary sources of process emissions are the smelting furnace and the refining kettle. Arsenic is present in several of the furnace feed materials and in all of the furnace products.⁴ The amount of arsenic in the feed material may vary greatly. In smelting operations, arsenic-containing materials are subjected to high furnace temperatures and either oxidizing or reducing temperatures. In certain oxidizing environments (e.g., reverberatory furnaces), arsenic trioxide can be formed and subsequently vaporize and leave with the offgases. In addition, arsenic can become complexed in the slag and exit the furnace with this stream.

The three main sources of process fugitive arsenic emissions are the charging operation, the slag tapping operation, and the metal pouring operation. As expected, the magnitude of arsenic emissions would vary with the arsenic content of the charge material. Emissions from

TABLE 5-3. ARSENIC EMISSION FACTORS FOR SECONDARY LEAD SMELTING FACILITIES

SCC	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Range in lb/ton ^a	Emission Factor Rating	Reference
3-04-005	Smelting Furnace	Fabric Filter	6.2×10^{-4}	--	U	7
3-04-004	Blast Furnace (Afterburner Outlet)	Afterburner	$< 1.5 \times 10^{-1}$	$1.1 \times 10^{-1} - 1.8 \times 10^{-1}$	U	8
3-04-004	Area Emission Material Storage and Handling	Uncontrolled	1.2×10^{-1}	--	U	4
3-04-004	Fugitives (Furnace Charging and Tapping)	Fabric Filter	5.6×10^{-2}	--	U	4
3-04-004	Blast and Reverberatory Furnaces	Fabric Filter/Wet Scrubber	2.8×10^{-3}	--	U	7
3-04-004-03	Blast Furnace	Afterburner/Cyclones Fabric Filter	2.9×10^{-4} lb/ton	--	U	9
3-04-004-14	Blast Furnace and Kettle Refining	Afterburner/Fabric Filter/Venturi Scrubber/Demister	3.0×10^{-4} lb/ton	--	U	9

^a Emission factors are expressed in lb of pollutant emitted per ton of lead produced. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

the charging operation include fine particulates and fumes, originating from recycled flue dusts which can contain significant amounts of arsenic. The slag and metal tapping operations incorporate high temperatures and therefore generate a considerable amount of fumes. Those fumes that are not captured and controlled represent process fugitive emissions.

Fugitive nonprocess arsenic emissions will be affected by the arsenic content of the various fine materials being stored at the smelter including the non-agglomerated flue dusts and the dried battery mud. The flue dust storage pile in the charge preparation area is the primary source of nonprocess fugitive arsenic emissions at a secondary lead smelting facility.⁴ In addition, battery breaking yards, battery storage areas, slag storage areas, and smelter access roads have all been identified as potential sources of nonprocess fugitive arsenic emissions. Meteorological factors (in particular the amount of wind and rain) and the amount of activity around the plant site can influence the total amount of arsenic from this source.⁴

5.2.4 Source Locations

In 1990, primary and secondary smelters in the United States produced 1,380,000 tons of lead. Secondary lead smelters produced 946,000 tons or about 69 percent of the total refined lead produced in 1990.⁵ Table 5-4 lists U.S. secondary lead smelters according to their annual lead production capacity.⁵

5.3 Primary Copper Production

5.3.1 Source Description

Seven primary copper smelters were operating in the United States in 1995 and one more was closed for modifications. The combined production capacity in 1995 for the seven plants in operation was 1,728,043 tons.¹⁰

TABLE 5-4. U.S. SECONDARY LEAD SMELTERS GROUPED ACCORDING TO ANNUAL LEAD PRODUCTION CAPACITY

Smelter	Location
<u>Small-Capacity Group:</u> ^a	
Delatte Metals ^b	Ponchatoula, LA
General Smelting and Refining Company	College Grove, TN
Master Metals, Inc. ^b	Cleveland, OH
Metals Control of Kansas ^b	Hillsboro, KS
Metals Control of Oklahoma ^b	Muskogee, OK
<u>Medium-Capacity Group:</u> ^c	
Doe Run Company	Boss, MO
East Penn Manufacturing Company	Lyon Station, PA
Exide Corporation	Muncie, IN
	Reading, PA
GNB, Inc.	Columbus, GA
	Frisco, TX
Gulf Coast Recycling, Inc.	Tampa, FL
Refined Metals Corporation ^b	Beech Grove, IN
	Memphis, TN
RSR Corporation	City of Industry, CA
	Middletown, NY
Schuylkill Metals Corporation	Forest City, MO
Texas Resources, Inc. ^b	Terrell, TX
<u>Large-Capacity Group:</u> ^d	
Gopher Smelting and Refining, Inc.	Eagan, MN
GNB, Inc.	Vernon, CA
RSR Corporation	Indianapolis, IN
Sanders Lead Company	Troy, AL
Schuylkill Metals Corporation	Baton Rouge, LA

Source: Reference 5.

^a Less than 22,000 tons.

^b These facilities were not operating as of January 1995.

^c 22,000 to 82,000 tons.

^d Greater than 82,000 tons.

5.3.2 Process Description

The pyrometallurgical process used to extract copper from sulfide ore concentrates (“concentrates”) is based upon copper’s strong affinity for sulfur and its weak affinity for oxygen as compared to that of iron and other base metals in the ore. The purpose of smelting is to separate the copper from the iron, sulfur, and commercially worthless mineral materials generally referred to as “gangue.” All of the primary copper smelters currently produce anode copper from sulfur-bearing ores with the same basic processes:¹⁰

- matte smelting (i.e., smelting of concentrates to produce matte);
- matte converting (to produce blister copper); and
- refining of blister copper in an anode furnace (to produce anodes).

Copper concentrates are received by the smelter that typically contain 24 to 30 percent copper, 30 percent sulfur, 25 percent iron, and 10 to 20 percent oxides of silicon, calcium, aluminum, magnesium, and zinc (usually present as sulfide). (Copper-bearing ores typically contain 0.5 to 1 percent copper by weight. A froth-flotation process is utilized to produce the “concentrate.” This froth-flotation process may or may not be performed at the smelter site.) Concentrates also contain impurities, such as lead, arsenic, antimony, cadmium, chromium, cobalt, manganese, mercury, nickel, and selenium. These impurities are typically found in combined concentrations of less than one percent. The smelter may also receive copper scrap (for direct input into the converters), or may receive other non-concentrate inputs, such as precipitates, or copper “speiss.”

Incoming concentrates are typically dried before charging into a smelting furnace or reactor. Several types of smelting furnaces/reactors are currently utilized in the United States, including flash furnaces, CONTOP reactors, and IsaSmelt reactors. Figure 5-7 illustrates basic smelting operations.¹⁰

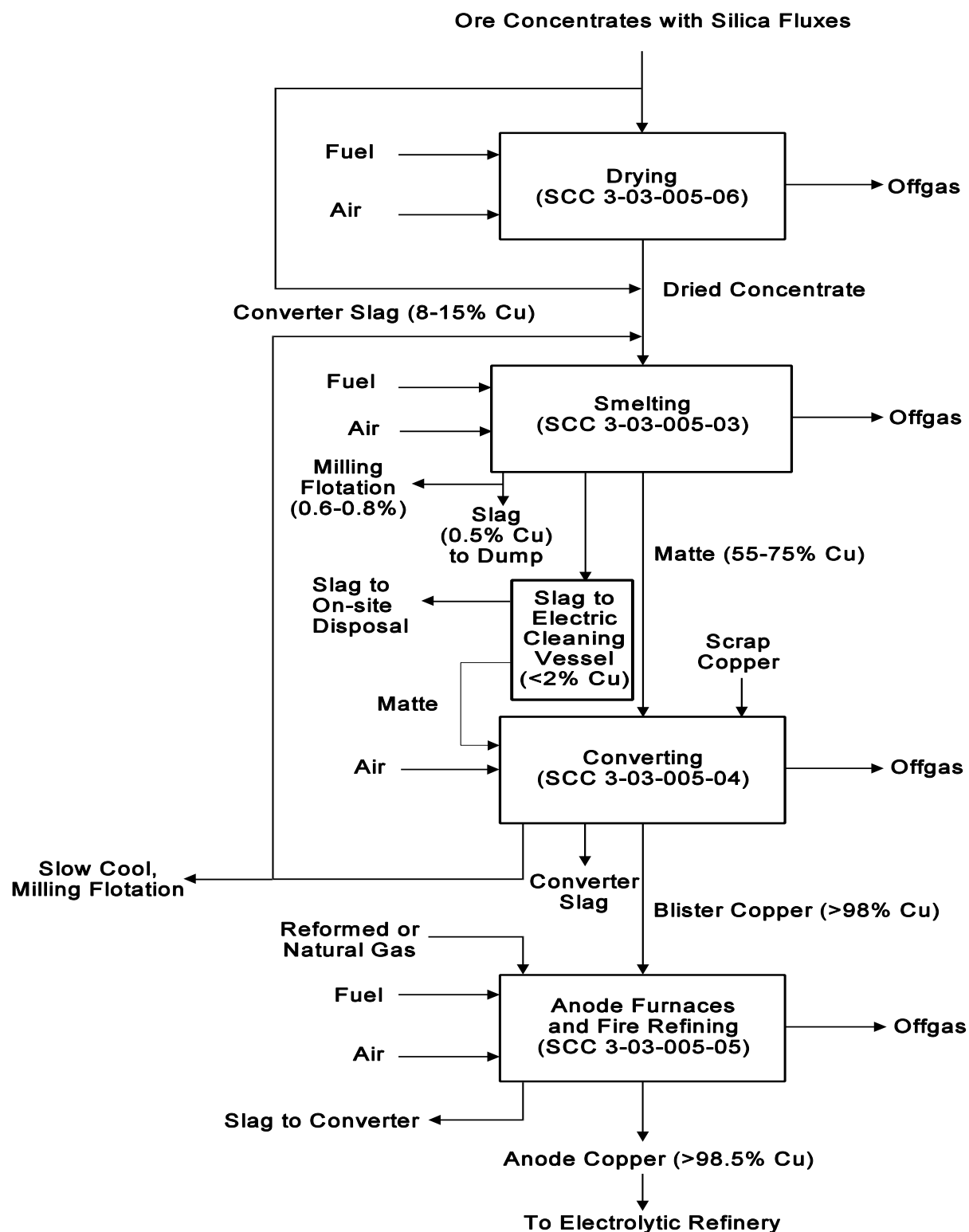


Figure 5-7. Typical Primary Copper Smelter Flow Sheet

Source: References 10 and 11.

The smelting furnace/reactor produces molten copper matte, typically containing 55-75 percent copper, which is tapped from the furnace, and transferred by ladles to converters. The smelting furnace/reactors also produces slag, containing relatively low amounts of copper (typically less than two percent). This slag may be discarded directly, if less than 1 percent copper, or may be transferred to an electric slag cleaning vessel (for further copper removal), or may be cooled and reconcentrated (again, in an attempt for further copper removal).

In the converters, further sulfur is removed from the matte, and in addition, iron is oxidized and separated by skimming. The output from the converters is “blister” copper, generally containing greater than 98 percent copper. Figure 5-8 illustrates a typical converter.¹²

Molten blister copper is poured from the converter, and transferred by ladles to anode furnaces, where further refining by removal of oxygen and other impurities takes place. The resulting “anode” copper is generally greater than 98.5 percent pure. It is cast into anodes for use in the final electrolytic refining step.

Further refining of “anode” copper into “cathode” copper (greater than 99.9 percent purity) is performed by electrolytic means in a “tank house.” Production of cathode copper may or may not take place at the smelter site.

5.3.3 Emissions

PM and SO₂ are the principal air contaminants emitted from primary copper smelters. Actual emissions from a particular smelter will depend upon the smelting configuration (type and mix of equipment used), control devices applied, and the operating and maintenance practices employed. Typically, arsenic will be emitted as PM. In addition, actual arsenic emissions will vary depending on the quantity of arsenic introduced to the smelter as copper-bearing feed materials. Table 5-5 presents arsenic emission factors available from one EPA report.¹³ In

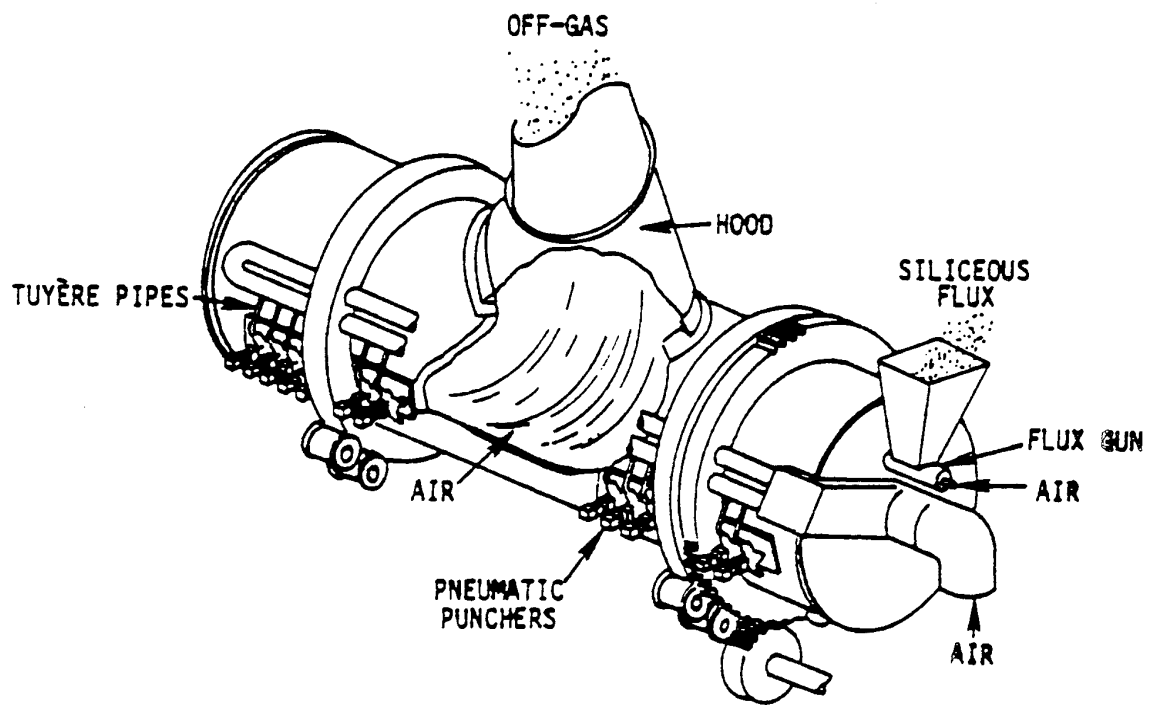


Figure 5-8. Copper Converter

Source: Reference 12.

TABLE 5-5. ARSENIC EMISSION FACTORS FOR PRIMARY COPPER SMELTING FACILITIES

SCC	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Range in lb/ton ^a	Emission Factor Rating
3-03-005-24	After Multiple Hearth Roaster, Reverberatory Furnace, Fluidized Bed Roaster, Electric Furnace	None	---	4.45 - 6.28	U
3-03-005-15	Converter/Fugitive Emissions	None	---	3.50×10^{-2} - 1.74×10^{-1}	U
3-03-005-14	Reverberatory Furnace - Fugitive Emissions	None	---	7.20×10^{-3} - 1.20×10^{-2}	U
3-03-005-09	Fluidized Bed Roaster	None	---	1.90×10^{-2} - 3.10×10^{-2}	U
3-03-005-02	Multiple Hearth Roaster	None	---	2.90×10^{-1} - 4.60×10^{-1}	U
3-03-005-03	Reverberatory Smelter (after Roaster)	None	---	1.80 - 9.37	U
3-03-005-04	Converter (all configurations)	None	---	2.00×10^{-4} - 1.40×10^{-3}	U
3-03-005-03	Reverberatory Smelter (after roaster)	ESP	---	8.00×10^{-2} - 2.60×10^{-1}	U
3-03-005-04	Converter (all configurations)	ESP	---	2.00×10^{-4} - 7.00×10^{-4}	U
		Baghouse	---	7.00×10^{-4} - 1.60×10^{-2}	U
3-03-005-09	Fluidized Bed Roaster	Venturi Scrubber	---	3.00×10^{-4} - 6.00×10^{-4}	U
3-03-005-13	Roasting - Fugitive Emissions	Spray Chamber/Cold ESP	---	4.40×10^{-3} - 1.6×10^{-2}	U
3-03-005-14	Reverberatory Furnace - Fugitive Emissions	Baghouse	---	7.40×10^{-3} - 8.70×10^{-3}	U
3-03-005-24	After Multiple Hearth Roaster, Reverberatory Furnace, Fluidized Bed Roaster, Electric Furnace	Spray Chamber/Baghouse	---	4.10×10^{-2} - 8.10×10^{-2}	U

Source: Reference 13.

^a Emission factors are expressed in lb of pollutant emitted per ton of concentrated ore processed. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

addition to process emissions, significant quantities of fugitive emissions are also generated during material handling operations and furnace charging and tapping.¹³

As a general observation, particulate emissions from primary smelting operations are predominantly metallic fumes in the submicrometer range. A variety of particulate contaminants are typically emitted during the roasting process. They vary in composition depending on the particular ore being roasted. Copper and iron oxides are the primary constituents, but other oxides such as those of arsenic, antimony, mercury, lead, cadmium, and zinc may also be present with metallic sulfates and sulfuric acid. Combustion products from fuel burning also contribute to the emissions from roasters and reverberatory smelting furnaces.

Fugitive particulates emitted from primary copper smelting consist primarily of metallic oxides and dust. Major sources of fugitive emissions are shown in Figure 5-9.¹⁰ Principal sources include ore concentrate unloading and handling, roaster calcine transfer operations, furnace tapping operations, and converter charging and skimming operations.

5.3.4 Emission Control Techniques

Control devices for particulate emissions from roasting, smelting, and converting operations include mechanical collectors (cyclones and settling flues), hot and cold ESPs, baghouses, and scrubbers. ESPs, usually preceded by mechanical collectors and operated at elevated temperatures, are by far the most common control devices.

The control techniques applied vary depending on smelter configuration, process equipment mix, emissions characteristics, and feasibility for SO₂ control. Off-gases from smelting equipment that produce relatively high concentrations of SO₂ (greater than 4 percent; includes fluidized bed roasters, non-reverberatory smelting furnaces, and converters) are generally treated in single- or double-contact sulfuric acid plants for SO₂ removal.

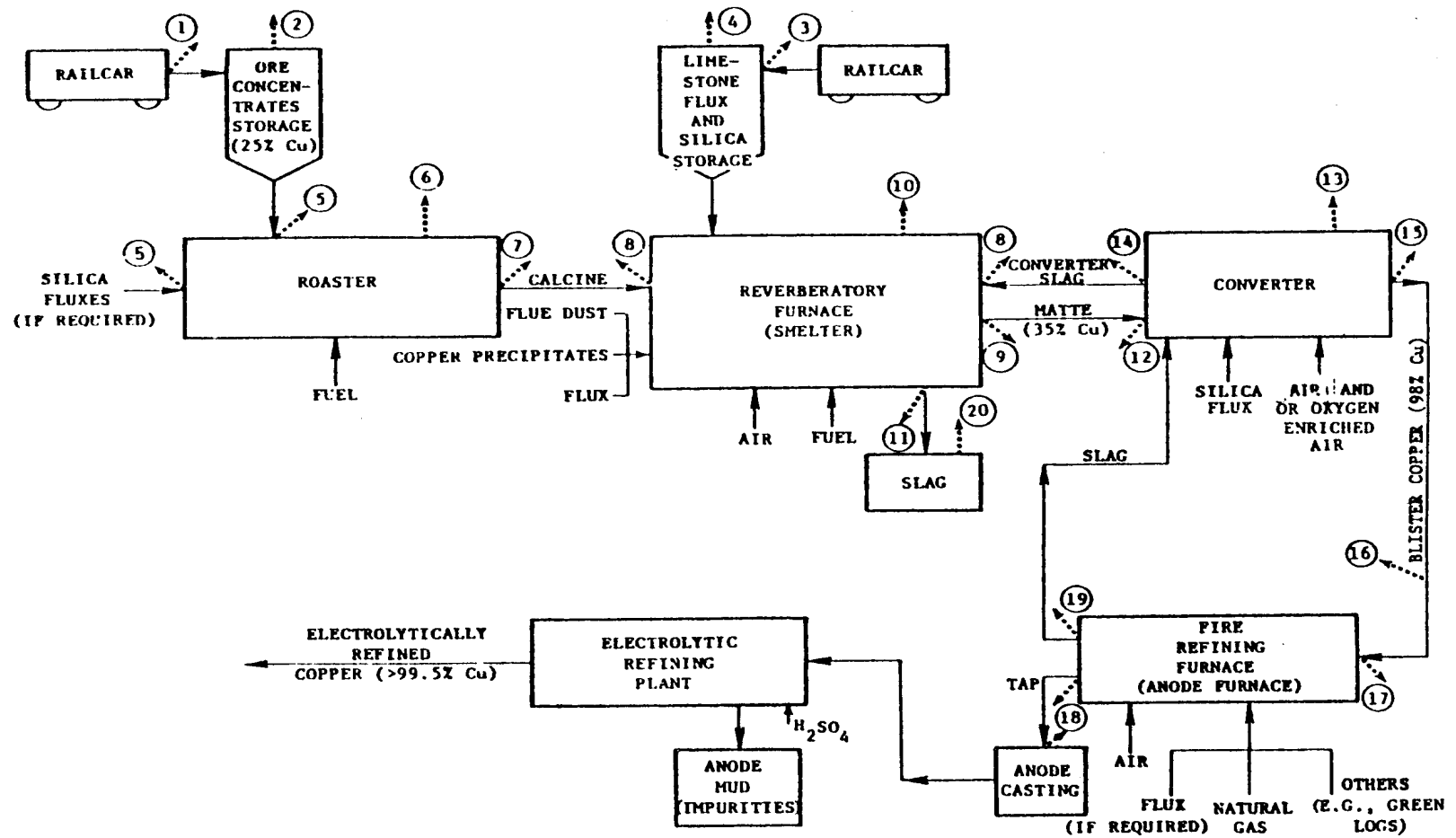


Figure 5-9. Fugitive Emission Sources at Primary Copper Smelters

Source: Reference 10.

Fugitive emissions produced by the majority of smelter fugitive sources, including concentrate handling, dried concentrate transfer, and furnace tapping (matte and slag), are controlled by enclosing the fugitive emission points in a hood and exhausting the captured emissions to a control device for collection. Fugitive emissions associated with converter operations are much more difficult to control. These emissions are substantial and occur during charging, skimming, or pouring operations when the converter mouth is rotated out from under the primary hood. They also result from primary hood leakage. Control techniques for converter fugitive emissions include secondary hoods of various designs and ventilating the converter building to a control device.³

5.3.5 Source Location

There are seven primary copper smelters in the United States. The names and locations of these seven smelters are listed in Table 5-6.¹⁰ Three facilities are located in Arizona, two in New Mexico, and one each in Texas and Utah.

TABLE 5-6. PRIMARY COPPER SMELTERS IN THE UNITED STATES

Owner/Operator	Location
ASARCO, Incorporated	El Paso, Texas
ASARCO, Incorporated	Hayden, Arizona
Cyprus Miami Mining Corporation	Claypool, Arizona
Kennecott Utah Copper Corporation	Magna, Utah
Broken Hill Propriety	San Manuel, Arizona
Phelps Dodge-Chino Mines Company	Hurley, New Mexico
Phelps Dodge Mining Company	Playas, New Mexico (Hidalgo County) ^a

Source: References 10 and 11.

^a Although the mailing address of the Phelps Dodge-Hidalgo smelter is Playas, New Mexico, the smelter is actually located in Hidalgo County, New Mexico.

5.4 Secondary Aluminum Operations

5.4.1 Source Description

Secondary aluminum operations involve the cleaning, melting, refining, alloying, and pouring of aluminum recovered from scrap, foundry returns, and dross. The processes used to convert scrap aluminum to secondary aluminum products such as lightweight metal alloy for industrial castings and ingots are presented in Figures 5-10 and 5-11.¹⁴ Production involves two general classes of operations: scrap treatment and smelting/refining.

5.4.2 Process Description

Scrap treatment involves receiving, sorting, and processing scrap to remove contaminants and prepare the material for smelting. Processes based on mechanical, pyrometallurgical, and hydrometallurgical techniques are used, and those employed are selected to suit the type of scrap processed.

The smelting/refining operation generally involves the following steps: (1) charging, (2) melting, (3) fluxing, (4) alloying, (5) mixing, (6) demagging, (7) degassing, (8) skimming, and (9) pouring. All of these steps may occur at each facility, with process distinctions being in the furnace type used and emissions characteristics. However, as with scrap treatment, not all of these steps are incorporated into the operations at a particular plant. Some steps may be combined or reordered, depending on furnace design, scrap quality, process inputs, and product specifications.¹⁴

Purchased aluminum scrap undergoes inspection upon delivery and is sorted into the categories shown in Figure 5-10. Clean scrap requiring no treatment is transported to storage or is charged directly into the smelting furnace. The bulk of the scrap, however, must be manually sorted as it passes along a steel belt conveyor. Free iron, stainless steel, zinc, brass, and oversize

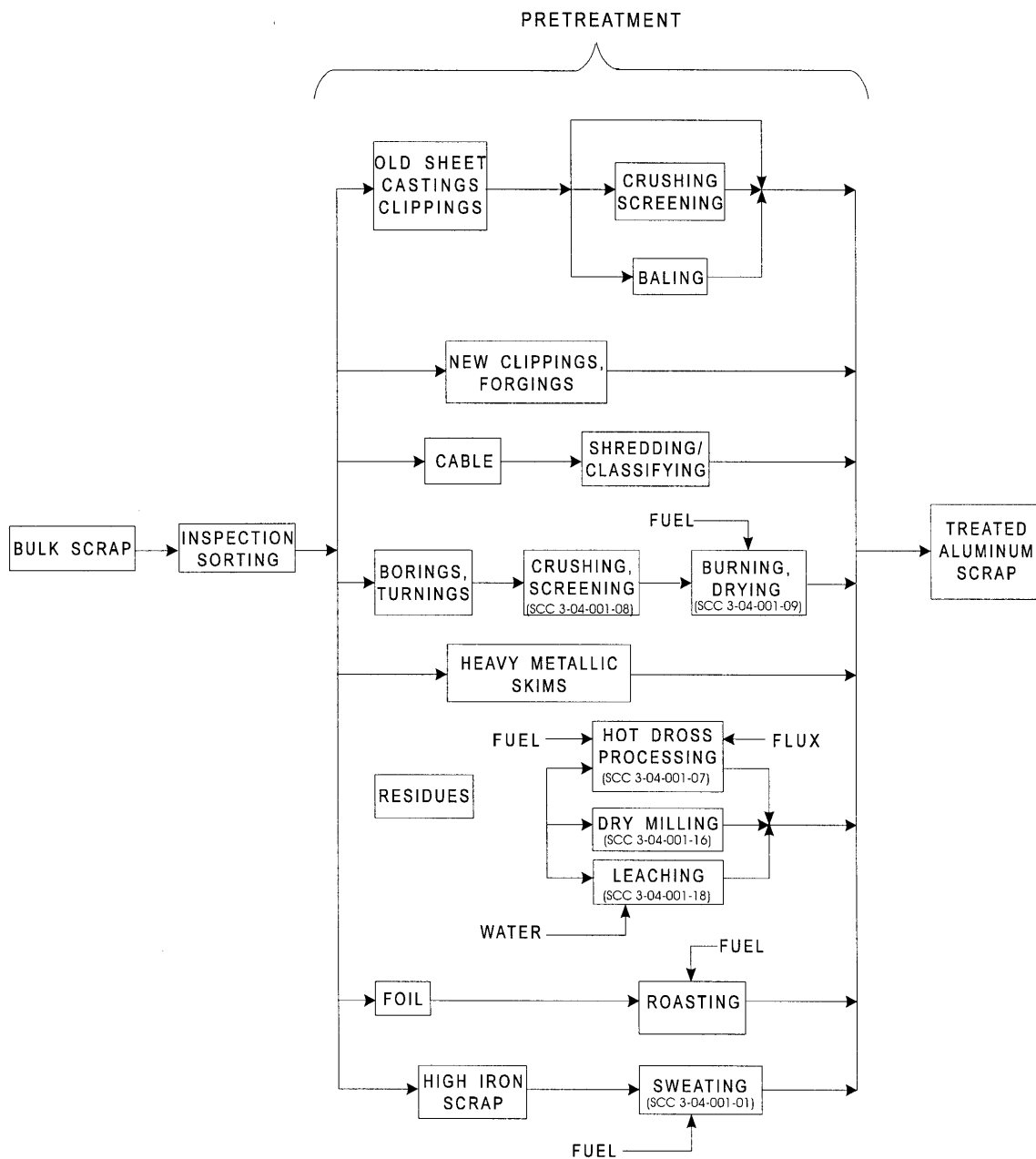


Figure 5-10. Typical Process Diagram for Pretreatment in the Secondary Aluminum Processing Industry

Source: Reference 14.

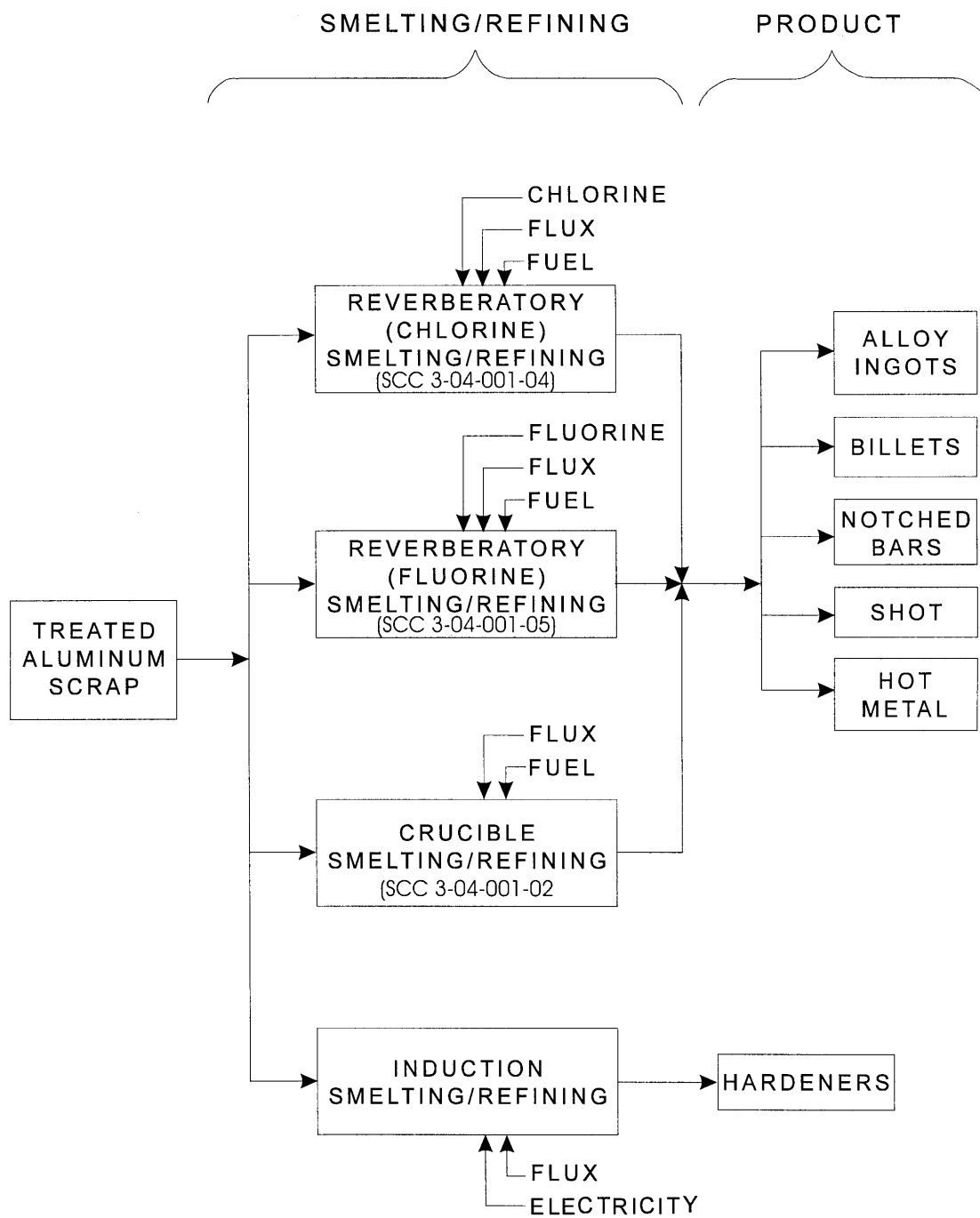


Figure 5-11. Typical Process Flow Diagram for the Secondary Aluminum Processing Industry

Source: Reference 14.

materials are removed. The sorted scrap then goes to appropriate scrap treating processes, if necessary, or is charged directly to the smelting furnace. The more common scrap treatment processes are discussed in the following paragraphs.

Sorted scrap is conveyed to a ring crusher or hammer mill where the material is shredded and crushed, and the iron is torn away from the aluminum. The crushed material passes over vibrating screens to remove dirt and fines, and tramp iron is removed by magnetic drums and/or belt separators. Baling equipment compacts bulky aluminum scrap into bales.

Pure aluminum cable with steel reinforcement or plastic insulation is cut by alligator-type shears and granulated or further reduced in hammer mills to separate the iron core and the plastic coating from the aluminum. Magnetic processing removes the iron and air classification separates the insulation. Borings and turnings, in most cases, are treated to remove cutting oils, greases, moisture, and free iron. The processing steps involved are (1) crushing, (2) drying to remove oil and moisture, (3) screening to remove aluminum fines, (4) removing iron magnetically, and (5) storing the clean dried borings in tote boxes.¹⁴

Several types of residue from primary and secondary aluminum plants contain recoverable amounts of aluminum. Aluminum is recovered from hot and cold drosses by batch fluxing in rotary furnaces. In the dry milling process, cold aluminum dross and other residues are processed by milling, screening, and concentrating to reduce oxides and non-metallic materials to fine powders, yielding a product which is 60 to 70 percent aluminum.

Drosses, skimmings, and slags are treated by leaching to remove fluxing salts and other nonrecoverable materials. First, the raw material is fed into a long, rotating drum or an attrition or ball mill, from which soluble contaminants are leached. The washed material is then screened to remove fines and dissolved salts and is dried and passed through a magnetic separator to remove ferrous materials. The non-magnetic materials are then stored or charged directly to the smelting furnace.

Aluminum foil is treated by roasting to separate carbonaceous materials associated with the aluminum.

Sweating is a pyrometallurgical process using open-flame reverberatory furnaces to recover aluminum from scrap with high iron content. The aluminum and other constituents with low-melting temperatures melt, trickle down the hearth, through a grate, and into molds or collecting pots. The materials with higher-melting temperatures, including iron, brass, and oxidation products formed during the sweating process, remain in the furnace until they are removed. Treated aluminum scrap is transferred to the smelting/refining operations for refinement into finished products.

In smelting/refining operations, reverberatory furnaces are commonly used to convert clean, sorted scrap, sweated pigs, or untreated scrap to ingots, shot, or hot metal. The scrap is first mechanically charged to the furnace, often through charging wells designed to introduce chips and light scrap below the surface of a previously melted charge (“heel”). Batch processing is generally practiced for alloy ingot production, and continuous feeding and pouring are generally used for products having less strict specifications.

Cover fluxes are used to prevent oxidation of the melt caused by air contact. Solvent fluxes react with non-metallic materials, such as burned coating residues and dirt, to form insoluble materials that float to the surface as part of the slag. Alloying agents are charged to the furnace in amounts determined by product specifications. Nitrogen or other inert gases can be injected into the molten metal to help raise dissolved gases (typically hydrogen) and intermixed solids to the surface.

Demagging reduces the magnesium content of the molten charge from approximately 0.3 to 0.5 percent (typical scrap value) to about 0.1 percent (typical product line alloy specification). When demagging with chlorine gas, chlorine is injected under pressure through carbon lances to react with magnesium and aluminum as it bubbles to the surface. Other

chlorinating agents or fluxes, such as anhydrous aluminum chloride or chlorinated organic compounds, are sometimes used.

In the skimming step, contaminated semi-solid fluxes (dross, slag, or skimmings) are ladled from the surface of the melt and removed through the forewell. The melt is then cooled before pouring.

The reverberatory (fluorine) process is similar to the reverberatory (chlorine) smelting/refining process, except that aluminum fluoride (AlF_3) is employed in the demagging step instead of chlorine. The AlF_3 reacts with magnesium to produce molten metallic aluminum and solid magnesium fluoride salt, which floats to the surface of the molten aluminum and is skimmed off.

The crucible smelting/refining process is designed to produce harder aluminum alloys by blending pure aluminum and hardening agents in an electric induction furnace. The process steps include charging scrap to the furnace, melting, adding and blending the hardening agent, skimming, pouring, and casting into notched bars.¹⁴

5.4.3 Emissions and Control

Each processing step in the secondary aluminum industry is a potential source of arsenic emissions, which are generally emitted as PM. Arsenic emissions will be a small fraction of total particulate emissions and will vary with the arsenic content of the scrap. Table 5-7 presents arsenic emission factors for specific processing units.^{15,16}

Data for arsenic emissions from secondary aluminum processing facilities were scarce. Currently, emissions data from secondary aluminum facilities are being collected for inclusion in the secondary aluminum MACT, which may augment the information provided here.

TABLE 5-7. ARSENIC EMISSION FACTORS FOR SECONDARY ALUMINUM PRODUCTION

SCC Number	Emission Source	Control Device	Emission Factor in lb/ton ^{a,b}	Emission Factor Range in lb/ton ^a	Emission Factor Rating	Reference
3-040-001-09	Burning/Drying	Venturi Scrubber	4.72×10^{-6}	$3.74 \times 10^{-6} - 5.78 \times 10^{-6}$	U	15
		Baghouse	$< 1.26 \times 10^{-6}$	$1.13 \times 10^{-6} - 1.54 \times 10^{-6}$	U	15
		Multiple Cyclones	2.12×10^{-5}	$1.67 \times 10^{-5} - 2.74 \times 10^{-5}$	U	16

^a Emission factors are expressed in lb of pollutant emitted per ton of aluminum cans processed. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

^b Detection limit used in emission factor calculation.

There is potential for particulate emissions from several processing steps, including crushing/screening, shredding/classifying, baling, burning/drying, dross processing, roasting, smelting/refining, and demagging. Particulate emissions may also be released by leaching operations during drying. Fumes may be emitted from fluxing reactions. Arsenic emission levels from each of these processes depends on the arsenic content of the feed introduced to each unit step.¹⁴

Typical control devices at secondary aluminum operations include baghouses, multicyclones, scrubbers, and local ventilation. These have been designed primarily for PM control; but in controlling PM, gaseous arsenic emissions are controlled.

5.5 Ferroalloy Production

5.5.1 Source Description

The term “ferroalloy” refers to an alloy of iron with some element other than carbon. Ferroalloys are typically used to impart distinctive qualities to steel and iron. Production of calcium carbide and silicon metal are also included in the ferrolloy source category (though they are not ferralloys) because they are manufactured using essentially the same equipment and processes.

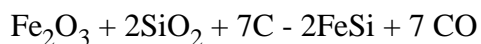
The ferroalloy industry is closely related to the iron and steel industries, its largest consumers. Ferroalloys provide unique qualities to steel and cast iron and serve important functions during iron and steel production cycles. The primary ferroalloys are those of chromium, manganese, and silicon. In addition, boron, cobalt, columbium, copper, molybdenum, nickel, phosphorus, titanium, tungsten, vanadium, zirconium, and the rare earths provide special characteristics and are often added as ferroalloys.

In 1989, the United States ferroalloy production was approximately 985,000 tons, significantly less than shipments in 1975 of approximately 1,770,000 tons. There were 28 companies that produced ferroalloys in 1989.¹⁷

5.5.2 Process Description

Ferroalloys are typically produced with submerged electric arc furnaces; however, exothermic (metallothermic) reaction furnaces and electrolytic cells can also be used to produce ferroalloys. Table 5-8 presents furnace descriptions along with their ferroalloy products. A typical ferroalloy plant is illustrated in Figure 5-12.¹⁷

Submerged electric arc furnaces usually produce a desired product directly, however, they may also produce an intermediate product that is subsequently used in additional processing methods. The submerged arc process is a reduction process. The reactants are made up of metallic ores (ferrous oxides, silicon oxides, manganese oxides, chrome oxides, etc.) and a carbon-source reducing agent, typically in the form of coke, charcoal, high- and low-volatility coal, or wood chips. Sometimes limestone is added as a flux material. Before being conveyed to a mix house for blending and weighing, raw materials are crushed, sized, and in some instances, dried. The processed material is then transported by conveyers, buckets, skip hoists, or cars to hoppers above the furnace. The mix is then gravity-fed through a feed chute as needed (i.e., continuously or intermittently). At high temperatures in the reaction zone, the carbon source reacts with metal oxides to form carbon monoxide and to reduce the ores to base metal. A typical reaction yielding ferrosilicon is presented below:



Smelting in an electric arc furnace is established by converting electrical energy to heat. As an alternating current is applied to the electrodes, current is forced to flow through the charge between the electrode tips. This produces a reaction zone at temperatures up to 3,632°F. The tip

TABLE 5-8. FERROALLOY PROCESSES AND RESPECTIVE PRODUCT GROUPS

Process	Product
Submerged arc furnace ^a	Silvery iron (15-22% Si) Ferrosilicon (50% Si) Ferrosilicon (65-75% Si) Silicon metal Silicon/manganese/zirconium (SMZ) High carbon (HC) ferromanganese Siliconmanganese HC ferrochrome Ferrochrome/silicon FeSi (90% Si)
Exothermic ^b Silicon reduction	Low carbon (LC) ferrochrome LC ferromanganese Medium carbon (MC) ferromanganese
Aluminum reduction	Chromium metal Ferrotitanium Ferrochromium Ferrovanadium
Mixed aluminothermal/silicothermal	Ferromolybdenum Ferrotungsten
Electrolytic ^c	Chromium metal Manganese metal
Vacuum furnace ^d	LC ferrochrome
Induction furnace ^e	Ferrotitanium

Source: Reference 17.

^a Process by which metal is smelted in a refractory-lined cup-shaped steel shell by submerged graphite electrodes.

^b Process by which molten charge material is reduced, in exothermic reaction, by addition of silicon, aluminum, or a combination of the two.

^c Process by which simple ions of a metal, usually chromium or manganese in an electrolyte, are plated on cathodes by direct low-voltage current.

^d Process by which carbon is removed from solid-state high-carbon ferrochrome within vacuum furnaces maintained at temperatures near melting point of alloy.

^e Process that converts electrical energy into heat, without electrodes, to melt metal charges in a cup or drum-shaped vessel

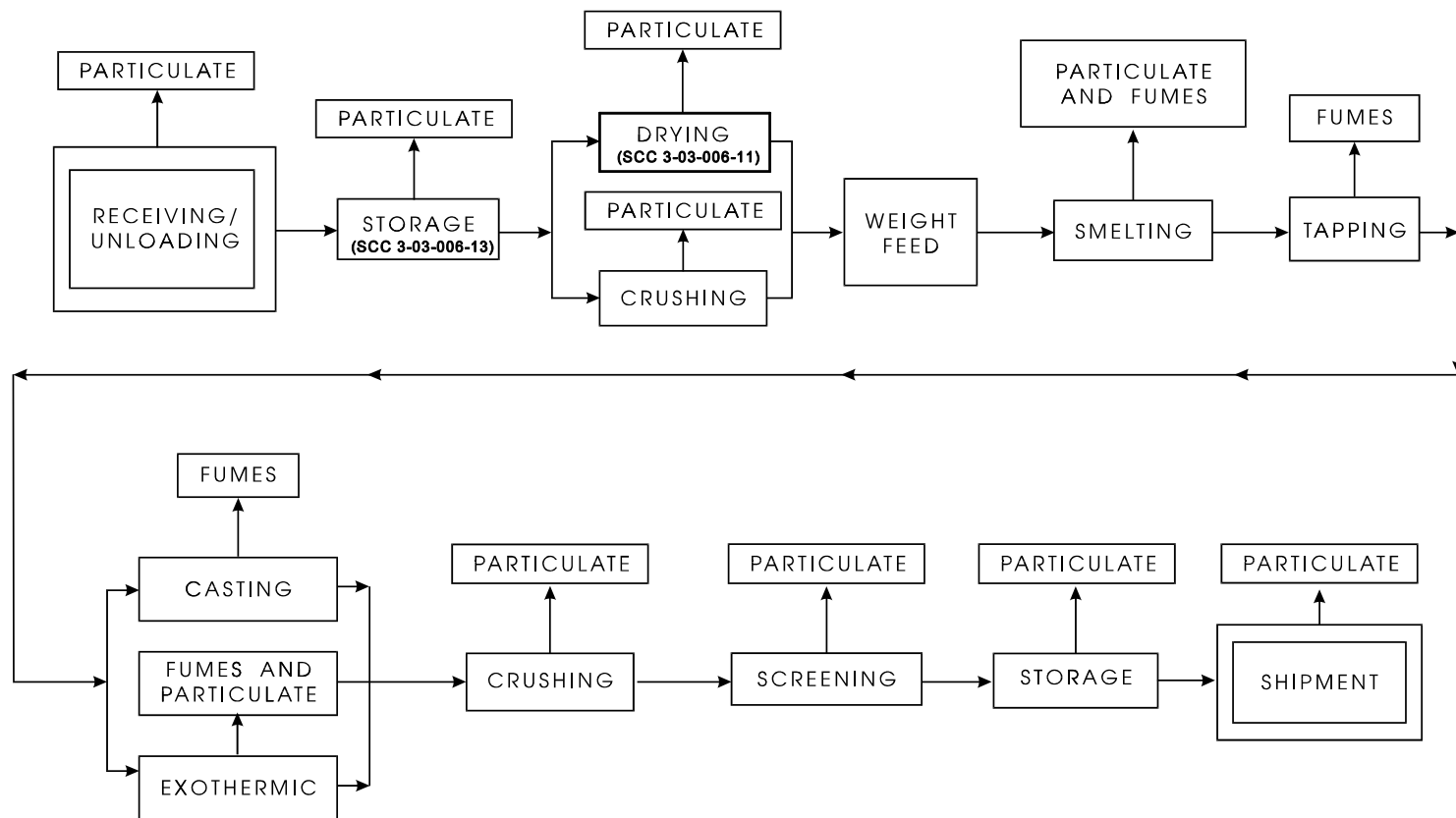


Figure 5-12. Typical Ferroalloy Production Process

Source: Reference 17.

of each electrode switches polarity continuously as the alternating current flows between the tips. A uniform electric load is maintained by continuously varying electrode depth by mechanical or hydraulic means.

Figure 5-13 depicts the design of a typical covered submerged electric arc furnace.¹⁷ The lower portion of the furnace is comprised of a cylindrical steel shell with a flat bottom or hearth. The shell is sometimes water-cooled to protect it from the heat of the process. For covered or semi-covered furnaces (but not for open-design furnaces), a water-cooled cover and fume collection hood are installed over the furnace shell. Typically, three carbon electrodes extend through the cover and into the furnace shell opening. Raw materials can be charged to the furnace through feed chutes from above the furnace. The surface of the furnace charge, which contains both molten material and unconverted charge during operation, is normally kept near the top of the furnace shell. The lower portions of the electrodes are placed at about 3 to 5 feet under the charge surface. Three-phase electric current arcs from electrode to electrode traveling through the charge material. As the electric energy is converted to heat, the charge material melts and reacts to form the desired product. The carbonaceous material in the furnace charge reacts with oxygen in the metal oxides of the charge and reduces them to base metals. This reaction generates large quantities of carbon monoxide that exits upwards through the furnace charge. The molten metal and slag are tapped through one or more tap holes protruding through the furnace shell at the hearth level. While power is applied continuously, feed material may be charged intermittently or continuously. Tapping, whether intermittent or continuous, is based on production rate of the furnace.¹⁷

There are two basic types of submerged electric arc furnaces, open and covered. The majority of the submerged electric arc furnaces in the U.S. are open furnaces. The open type furnaces have a fume collection hood at least 3.3 feet above the top of the furnace shell. In some situations, adjustable panels or screens are used to reduce the open space between the furnace and hood. This is also done to improve emissions capture efficiency. Fabric filters and ESPs are often used to control emissions from open furnaces.

CARBON ELECTRODES

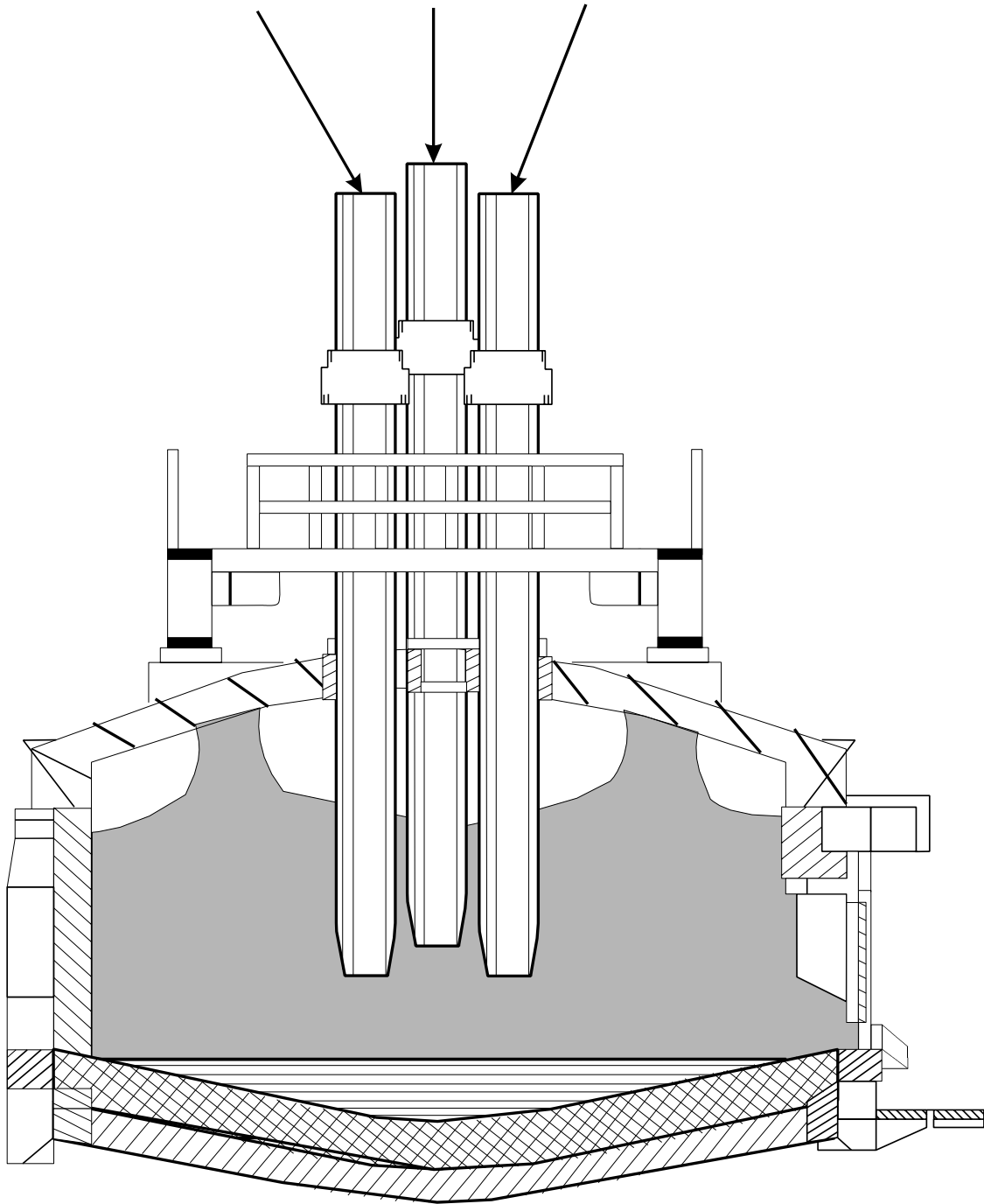


Figure 5-13. Typical Submerged Arc Furnace Design

Source: Reference 17.

Some covered furnaces have a water-cooled steel cover that fits closely to the furnace shell. The goal of covered furnaces is to limit air filtration into the furnace gases, thereby reducing combustion of the gas. In doing so, the volume of gas requiring collection and treatment is reduced. Holes in the cover allow for the charge and electrodes to pass through. Covered furnaces that partially close these hood openings with charge material are referred to as “mix sealed” or “semi-closed furnaces.” While these covered furnaces significantly reduce air infiltration, some combustion still occurs under the furnace cover. Covered furnaces equipped with mechanical seals around the electrodes and sealing compounds are referred to as “sealed” or “totally closed.” These types of furnaces have minimal, if any, air infiltration and undercover combustion.

Removal of the molten alloy and slag that accumulate on the furnace hearth is done through a tap hole. Typically this process takes 20 to 30 minutes. The molten metal and slag pour from the tap hole into a carbon-lined trough, then into a carbon-lined runner that directs the metal and slag into a reaction ladle, ingot molds, or chills.

After the large ferroalloy castings are allowed to cool and solidify, they may be broken with drop weights or hammers. Broken pieces are then crushed, screened (sized), and stored in bins until shipment.

The exothermic (metallothermic) process uses an intermediate molten alloy which may come directly from a submerged electric arc furnace or from another type of heating apparatus. The process is typically used to produce high-grade alloys with low-carbon content. As silicon and aluminum react with oxygen in the molten-alloy, low- and medium-carbon content ferrochromium and ferromanganese are produced. Aluminum reduction is used to produce chromium, ferrotitanium, ferrovanadium, and ferrocolumbium. A mixed alumino/silico thermal process is used to produce ferromolybdenum and ferrotungsten. Typically, exothermic processes are performed in open vessels and may have similar emissions to the submerged arc process for short periods during reduction.

Electrolytic processes are used to manufacture high-purity manganese and chromium. Electrolysis of an electrolyte taken from manganese ore or manganese-bearing ferroalloy slag is used to produce manganese. The following steps complete the process: (1) roasting the ore to convert it to manganese oxide, (2) leaching the roasted ore with sulfuric acid to solubilize manganese, (3) neutralization and filtration to extract iron and aluminum hydroxides, (4) purifying the leach liquor by treatment with sulfide and filtration to remove metals, and (5) electrolysis.

Electrolytic chromium is typically produced from high-carbon ferrochromium. Hydrogen gas is produced by dissolving the alloy in sulfuric acid. The leachate is treated with ammonium sulfate and conditioned to remove ferrous ammonium sulfate and produce a chrome-alum for feed to the electrolysis cells.¹⁷

5.5.3 Emissions and Controls

Particulate is generated from several operations during ferroalloy production. These operations include raw material handling, smelting, tapping, and product handling. Organic emissions are emitted almost entirely from smelting operations. The furnaces where smelting is completed are the primary (almost exclusive) sources of potential particulate and organic emissions. The reader is referred to Section 12.5 of AP-42 for particulate and size specific particulate emissions factors for submerged arc electric furnaces.¹⁷ Table 5-9 presents arsenic emission factors for semi-covered electric arc furnaces.¹⁸

Particulate emissions in the form of fumes from electric arc furnaces make up the vast majority (94 percent) of the total particulate emissions from the ferroalloy industry. In addition, substantial quantities of carbon monoxide and organic materials are emitted from electric arc furnaces. Organic emissions are much higher from covered furnaces than from open furnaces. In addition, dust is generated from a variety of activities including raw material storage and handling, heavy vehicle traffic, crushing, sizing and drying. Rotary and other types of dryers are

TABLE 5-9. ARSENIC EMISSION FACTORS FOR ELECTRIC ARC FURNACES

SCC	Emission Source	Control Device	Average Emission Factor in lb/MWh ^a	Emission Factor Range in lb/MWh ^a	Emission Factor Rating
3-03-007-01	Electric Arc Furnace	None	2.64×10^{-2}	NA	U
3-03-007-02	Electric Arc Furnace ^b	None	1.90×10^{-3}	NA	U
3-03-007-02	Electric Arc Furnace ^c	Venturi Scrubber	1.30×10^{-4}	NA	U

Source: Reference 18.

^a Emission factor is expressed in lb of pollutant emitted per MWh of energy consumed by furnace. To convert to kg/MWh, multiply by 0.454.

^b Semi-sealed, ferrosilicon production.

^c Sealed, silicomanganese production.

often used to dry raw materials. These dryers can generate substantial quantities of particulate emissions.

The majority of open electric arc furnaces are controlled with fabric filters, although to a much lesser extent, scrubbers and electrostatic precipitators are also used.

For covered furnaces, two emission capture systems are necessary. While a primary capture system is used to withdraw gases from under the furnace cover, a secondary system captures fumes released around the electrode seals during tapping. Scrubbers are the most common control device used to control exhaust gases from sealed furnaces. Afterburners are always used to burn off CO after control devices for covered furnaces.

Tapping operations also generate fumes. Some plants capture these emissions with a main canopy hood, while others use separate tapping hoods ducted to either the furnace emissions control device or a separate control device.

Dust from pretreatment activities may be controlled by dust collection equipment such as scrubbers, cyclones, or fabric filters.

5.6 Iron and Steel Foundries

5.6.1 Process Description

Iron and steel foundries produce gray, white, ductile, or malleable iron and steel castings. Both cast irons and steels are solid solutions of iron, carbon, and various alloying materials. Although there are many types of iron and steel, groups can be distinguished by their carbon composition. Cast iron typically contains 1 percent carbon or greater; cast steel usually contains less than 1 percent carbon.^{18, 19}

Iron castings are used in many types of equipment, including motor vehicles, farm machinery, construction machinery, petroleum industry equipment, electrical motors, and iron and steel industry equipment.

Steel castings are used in railroad equipment, construction machinery, motor vehicles, aircraft, agricultural equipment, ore refining machinery, and chemical manufacturing equipment.¹⁸ Steel castings are classified on the basis of their composition and heat treatment, which is determined by their end use. Classifications include carbon, low-alloy, heat-resistant, corrosion-resistant, and wear-resistant.

The following four basic operations are performed in all iron and steel foundries:

- Storage and handling of raw materials;
- Preparation of the molds to shape the molten metal;
- Melting of the raw materials; and
- Pouring of hot molten metal into molds.

Other processes present in most foundries include:

- Sand preparation and handling;
- Mold cooling and shakeout;
- Casting cleaning, heat treating, and finishing;
- Coremaking;
- Pattern making; and
- Sand reclamation.

A generic process flow diagram for iron and steel foundries is shown in Figure 5-14.¹⁸

Figure 5-15 depicts the emission points in a typical iron foundry.¹⁷

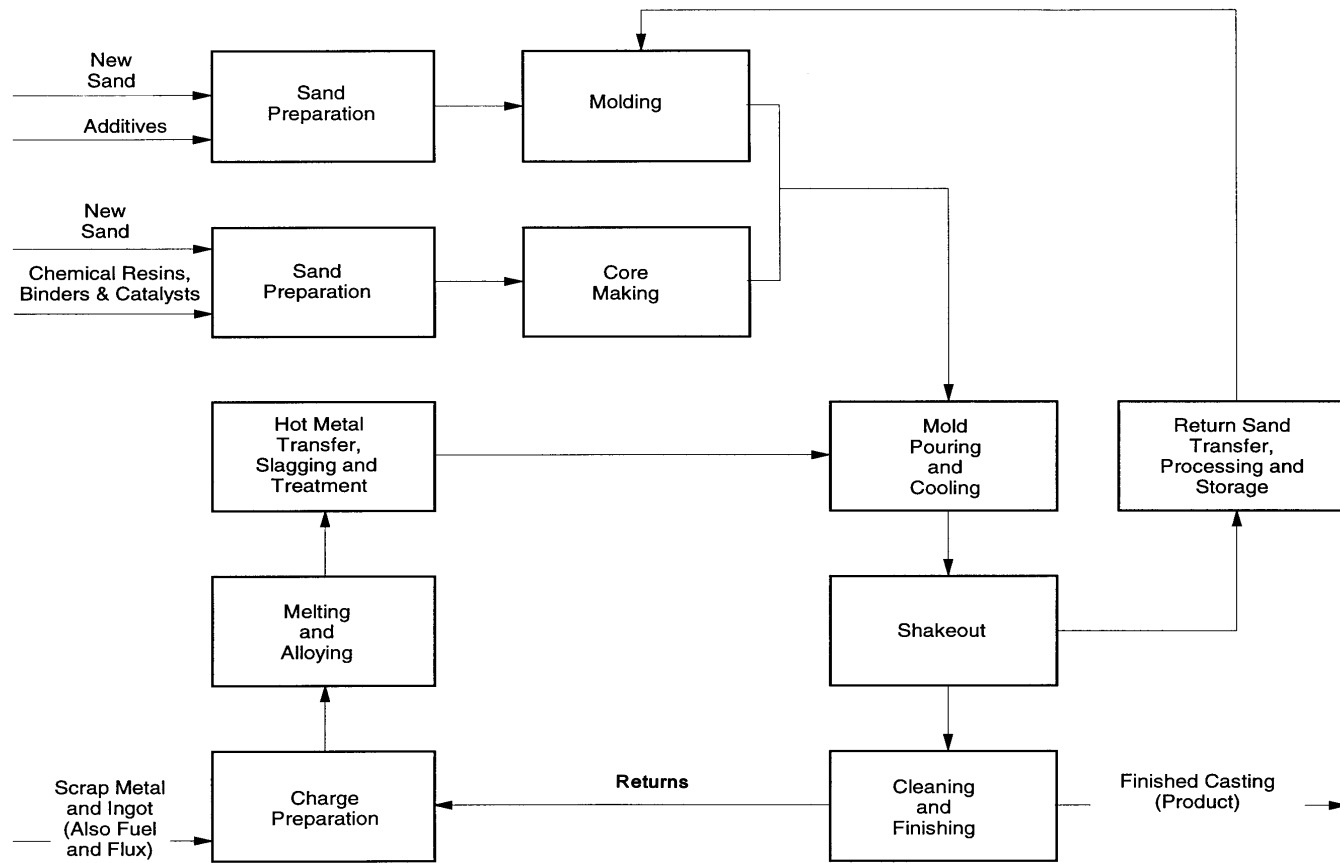


Figure 5-14. Process Flow Diagram for a Typical Sand-Cast Iron and Steel Foundry

Source: References 18 and 20.

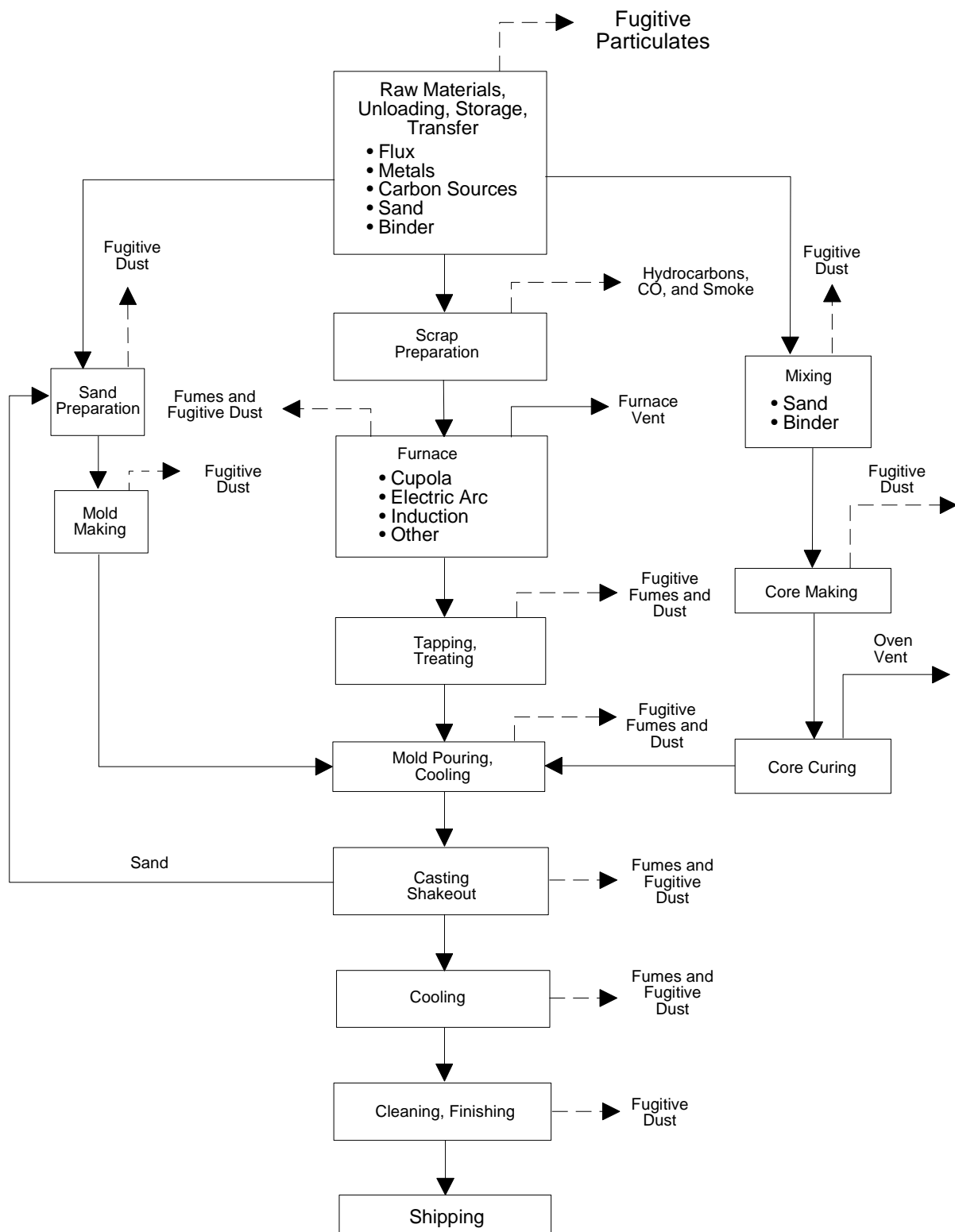


Figure 5-15. Emission Points in a Typical Iron and Steel Foundry

Source: References 17 and 20.

Metal Melting Process

In a typical foundry operation, charges to the melting unit are sorted by size and density and cleaned (as required) prior to being put into the melter. Charges consist of scrap metal, ingot, carbon (coke), and flux. Prepared charge materials are weighed and transferred into the melting furnace by crane buckets, skip hoists, or belt feeders. The charge in an electric furnace or cupola is heated until it reaches a certain temperature and the desired product chemistry of the melt has been attained. After the desired product is obtained, the molten metal is either poured out of the furnace into various-size transfer ladles and then into the molds or it is transferred to holding furnaces for later use.

The metal melting process in iron and steel foundries is accomplished in cupolas and in electric arc furnaces (EAFs) and electric induction furnaces (EIFs). Cupolas are used to melt iron for casting and are charged with alternate layers of coke, metallics, and fluxes. Combustion air is introduced into the cupola through tuyeres located at the base. The heat produced by the burning coke melts the iron, which flows down and is tapped from the bottom of the cupola. Fluxes combine with impurities in the charge and form slag, which is removed through tap holes located above the level of the metal tap hole. Cupola capacities range primarily from 1 to 30 tons per hour, with a few large units capable of producing close to 100 tons per hour. Larger furnaces are operated continuously for several days with inspections and cleanings between operating cycles.²¹

Iron and steel castings are produced in a foundry by pouring molten metal into molds made of sand, metal, or ceramic material. Steel foundries rely on EAFs or induction furnaces for melting purposes. In all types of foundries, when the metal has solidified, the molds are destroyed and the castings are removed on a shakeout unit. Abrasive (shotblasting) cleaning, grinding, and heat treating are performed as necessary. The castings are then inspected and shipped to plants of other industries for machining and assembly into a final product.¹⁸

Mold and Core Production

In addition to melting, the casting or mold pouring and cooling operations in iron and steel foundries are suspected to be a source of arsenic emissions. Also, mold preparation and casting shakeout (removal from the mold) activities are also suspect as arsenic emission sources, although test data are not available to quantify actual arsenic emissions.

5.6.2 Emission Control Techniques

Control technologies commonly used to control arsenic emissions from iron and steel foundry metal melting operations include baghouses and wet scrubbers. Fugitive emissions from molding, casting, and shakeout are generally controlled with local hooding or building ventilation systems that are ducted to a control device (predominantly baghouses).²¹

5.6.3 Emission Factors

Arsenic emission factors were available for an arc furnace in a steel mill and cupola within an iron foundry. These emission factors are presented in Table 5-10.^{22,23}

5.6.4 Source Locations

There were 756 iron and steel foundries in the United States in 1992 based on a survey conducted by the EPA in support of the iron and steel foundry Maximum Achievable Control Technology (MACT) standard development.²⁴ In general, foundries are located in areas of heavy industry and manufacturing, especially areas where iron and steel are produced (e.g., the Great Lakes States).

TABLE 5-10. ARSENIC EMISSION FACTORS FOR IRON AND STEEL FOUNDRIES

SCC Number	Emission Source	Control Device	Emission Factor in lb/ton ^a	Emission Factor Range in lb/ton ^a	Emission Factor Rating	Reference
3-09-001-98	Fabricated Metal Products: Arc Furnace	Baghouse	5.62×10^{-6} (steel produced)	4.37×10^{-6} - 7.49×10^{-6}	U	22
3-04-003-01	Iron Foundry - Cupola ^b	None	3.24×10^{-5}	---	U	23
		Baghouse	$< 9.89 \times 10^{-6}$	$< 6.17 \times 10^{-6}$ - 1.71×10^{-6}	U	23

^a Emission factors are expressed in lb of pollutant emitted per ton of cast pipe produced. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

^b Process provides molten iron for production of centrifugally-cast iron pipe. Raw materials include pig iron, scrap iron, steel, scrap, coke, and limestone.

“---” means data not available.

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SECTION 6.0

EMISSIONS OF ARSENIC AND ARSENIC COMPOUNDS FROM THE PULP AND PAPER INDUSTRY

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers. Kraft pulping is the major form of chemical wood pulping in the United States, accounting for approximately 85 percent of pulp production,¹ and is expected to continue as the dominant pulping process.^{2,3} Semi-chemical and acid sulfite pulping constitute 6 and 4 percent of domestic pulp production, respectively.¹

Four processes associated with the pulp and paper industry have been identified as potential sources of arsenic emissions: chemical recovery furnaces, smelt dissolving tanks, lime kilns, and power boilers. The following sections focus on the pulp mill thermal chemical recovery processes associated with potential arsenic emissions. Arsenic emissions from wood waste and fossil fuel-fired industrial power boilers are not specific to the pulp and paper industry and are discussed in Sections 4.1.1 and 4.1.2.

6.1 Kraft Recovery Furnaces And Smelt-Dissolving Tanks

6.1.1 Process Description

The kraft pulping process involves the cooking or digesting of wood chips at an elevated temperature (340 to 360°F) and pressure (100 to 135 psig) in white liquor, which is a water solution of sodium sulfide (Na_2S) and sodium hydroxide (NaOH). The lignin that binds the cellulose fibers is chemically dissolved by the white liquor in a tall, vertical digester. This process breaks the wood into soluble lignin and alkali-soluble hemicellulose and insoluble cellulose or pulp. A typical kraft pulping and recovery process is shown in Figure 6-1.⁴

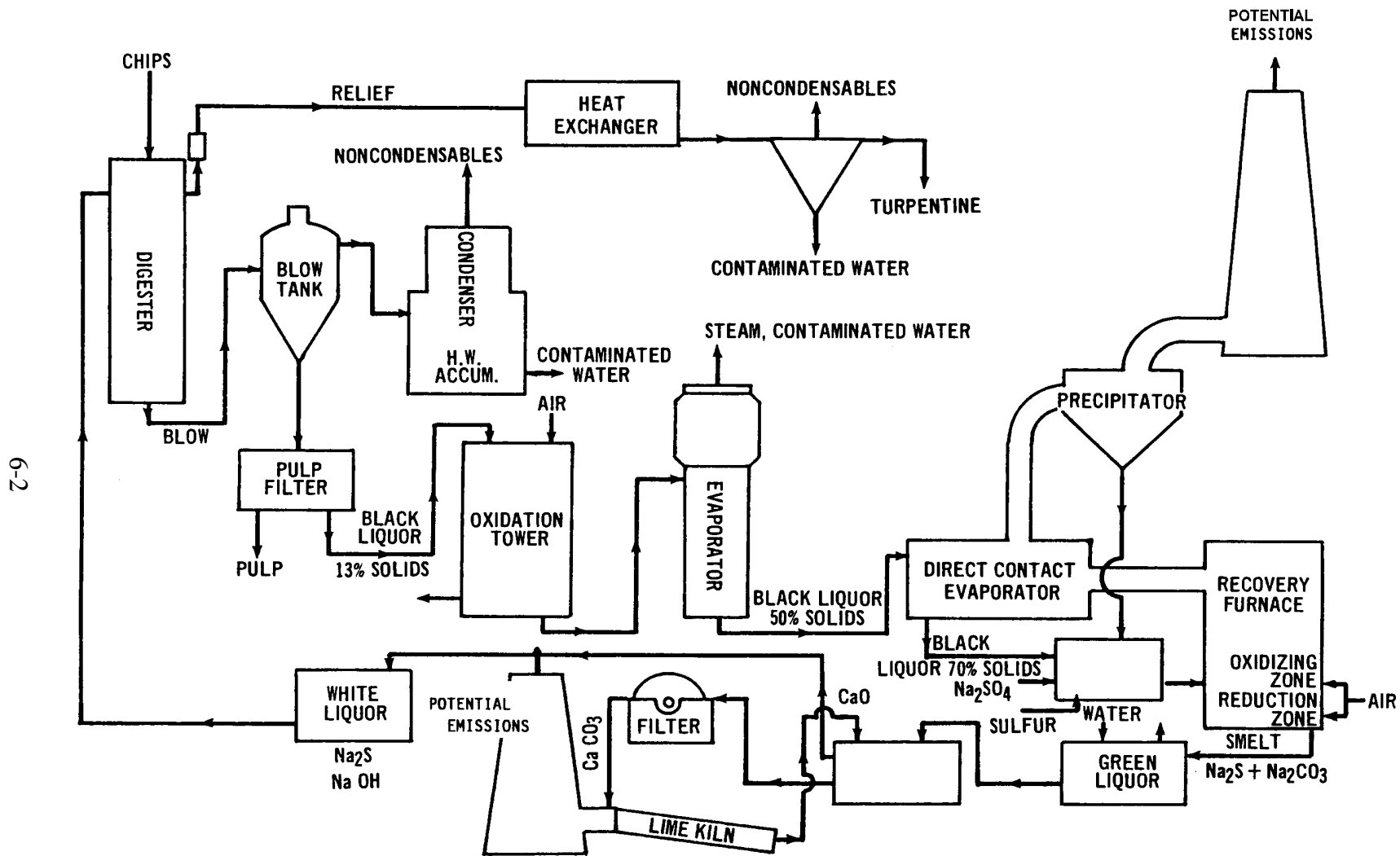


Figure 6-1. Typical Kraft Pulp and Recovery Process

Source: Reference 4.

Two types of digester systems are used in chemical pulping: batch and continuous. In a batch digester, the contents of the digester are transferred to an atmospheric tank (usually referred to as a blow tank) after cooking is completed (2 to 6 hours). In a continuous digester, wood chips and white liquor continuously enter the system from the top while pulp is continuously withdrawn from the bottom into a blow tank. In both types of digesters, the entire contents of the blow tank are diluted and pumped to a series of brownstock washers, where the spent cooking liquor is separated from the pulp. The pulp, which may then be bleached, is pressed and dried into the finished product.

The balance of the kraft process is designed to recover the cooking chemicals and heat. The diluted spent cooking liquor, or weak black liquor, which is 12 to 18 percent dissolved solids, is extracted from the brownstock washers and concentrated in a multiple-effect evaporator system to about 55-percent solids. The liquor is then further concentrated to 65-percent solids (strong black liquor) in a direct contact evaporator (DCE) or a nondirect contact evaporator (NDCE), depending on the configuration of the recovery furnace in which the liquor is combusted. DCE and NDCE recovery furnace schematics are shown in Figures 6-2 and 6-3, respectively.⁵

In older recovery furnaces, the furnace's hot combustion gases concentrate the black liquor in a DCE prior to combustion. NDCEs include most furnaces built since the early 1970s and modified older furnaces that have incorporated recovery systems that eliminate conventional DCEs. These NDCEs use a concentrator rather than a DCE to concentrate the black liquor prior to combustion. In another type of NDCE system, the multiple-effect evaporator system is extended to replace the direct contact system.

The strong black liquor is sprayed into a recovery furnace with air control to create both reducing and oxidizing zones within the furnace chamber. The combustion of the organics dissolved in the black liquor provides heat for generating process steam and, more importantly, for reducing sodium sulfate (Na_2SO_4) to Na_2S to be reused in the cooking process. Na_2SO_4 , which constitutes the bulk of the particulates in the furnace flue gas, is recovered and recycled by an ESP. After combustion, most of the inorganic chemicals present in the black liquor collect as

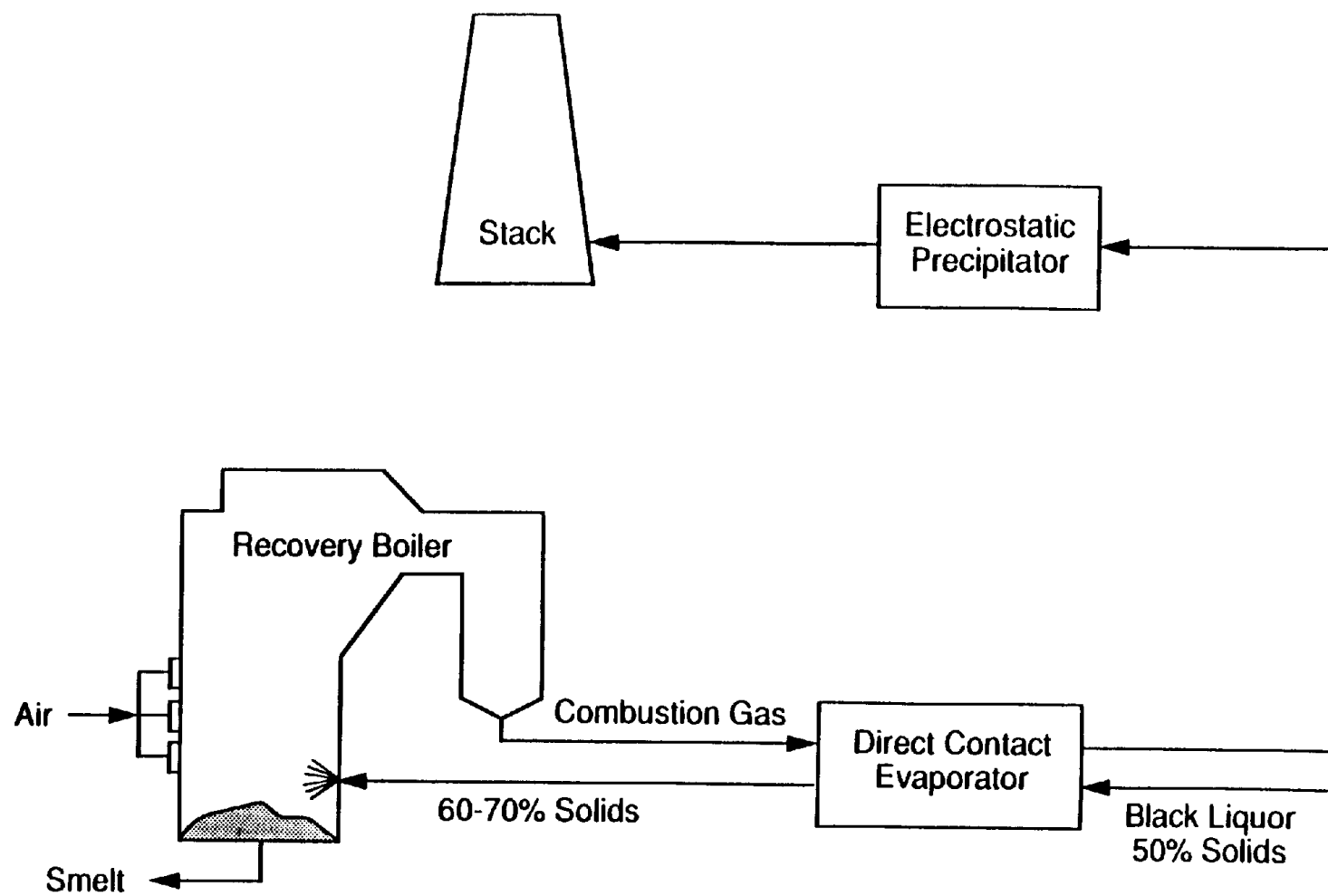


Figure 6-2. Direct Contact Evaporator Recovery Boiler

Source: Reference 5.

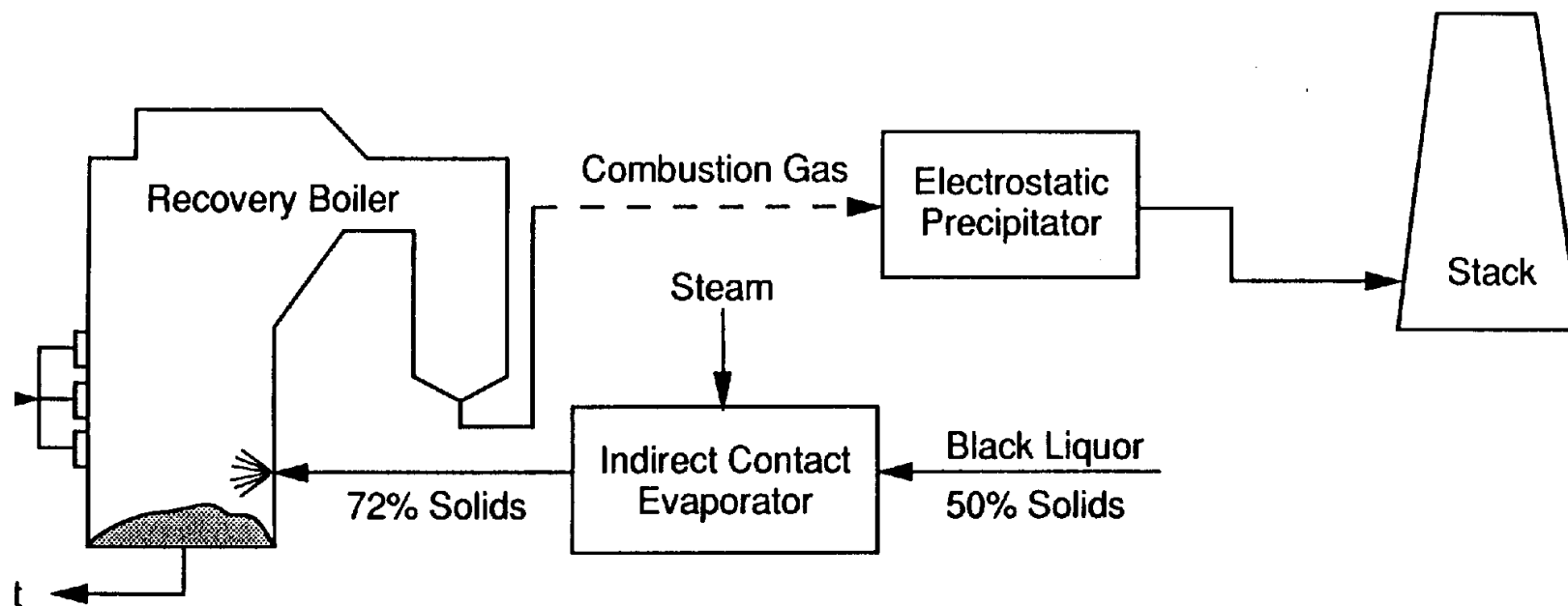


Figure 6-3. Nondirect Contact Evaporator Recovery Boiler

Source: Reference 5.

a molten smelt (containing sodium carbonate [Na_2CO_3] and Na_2S) at the bottom of the furnace, where they are continuously withdrawn into a smelt-dissolving tank. Molten smelt in the smelt-dissolving tank is contacted with mill water or weak wash (the filtrate from lime mud washing) to form green liquor.

In addition to straight kraft process liquor, semi-chemical pulping process spent liquor, known as brown liquor, may also be recovered in kraft recovery furnaces. The semi-chemical pulping process is a combination of chemical and mechanical pulping processes that was developed to produce high-yield chemical pulps. In the semi-chemical process, wood chips are partially digested with cooking chemicals to weaken the bonds between the lignin and the wood. Oversize particles are removed from the softened wood chips and the chips are mechanically reduced to pulp by grinding them in a refiner. The most common type of semi-chemical pulping is referred to as neutral sulfite semi-chemical (NSSC). A major difference between the semi-chemical process and the kraft/sulfite pulping process is that the semi-chemical digestion process is shorter and wood chips are only partially delignified. Some semi-chemical pulp mills are, as of 1997, using chemical recovery.⁶ Also, as mentioned above, some mills combine spent liquor from on-site semi-chemical process with spent liquor from adjacent kraft process for chemical recovery.¹

Particulate emissions from the kraft recovery furnaces consist primarily of Na_2SO_4 and Na_2CO_3 , with some sodium chloride. Particulate emissions also contain arsenic, but only in minute quantities because arsenic is found as a contaminant in process chemicals and in trace amounts in wood. Particulate control and, therefore, arsenic control on recovery furnaces is achieved with ESPs, including both wet- and dry-bottom and, to a lesser extent, with scrubbers. Further particulate control is necessary for DCEs equipped with either a cyclonic scrubber or a cascade evaporator because these devices are generally only 20- to 50-percent efficient for particulates.⁴ Most often in these cases, an ESP is employed after the DCE for an overall particulate control efficiency range of 85 percent to more than 99 percent. At existing mills, auxiliary scrubbers may be added to supplement older and less efficient primary particulate control devices. No specific data were available in the literature documenting lead control efficiencies for ESPs and scrubbers on kraft black liquor recovery furnaces.

6.1.2 Emission Factors

Emission factors for arsenic from kraft recovery furnaces were developed from data provided by the National Council for Air and Stream Improvement (NCASI), an industry environmental research organization.^{7,8} Kraft furnace/control configurations represented included a DCE recovery furnace equipped with an ESP and scrubber in series, a DCE recovery furnace equipped with only an ESP, an NDCE recovery furnace equipped with an ESP and scrubber in series, and an NDCE recovery furnace equipped with only an ESP. Emissions data were also provided for smelt-dissolving tanks (3). Arsenic emission factors for kraft black liquor recovery furnaces and smelt-dissolving tanks are presented in Table 6-1.

6.1.3 Source Locations

The distribution of kraft pulp mills in the United States in 1997 is shown in Table 6-2.⁶ Kraft pulp mills are located primarily in the southeast, whose forests provide over 60 percent of U.S. pulpwood.¹

6.2 Lime Kilns

6.2.1 Process Description

In the kraft process, green liquor from the smelt-dissolving tanks is clarified and reacted with burnt lime (CaO) in a lime slaker. Following a series of causticizing vessels, the resultant white liquor is clarified to yield $\text{Na}_2\text{S} + \text{NaOH}$ (aqueous white liquor) and lime mud or calcium carbonate (CaCO_3). The white liquor is recycled to the digestion process and the lime mud is calcined in a lime kiln to regenerate CaO .⁵

A lime kiln is a countercurrent, inclined tube process heater designed to convert lime mud (CaCO_3) to CaO for reuse in the causticizing of kraft liquor. A process flow diagram for a lime kiln is shown in Figure 6-4. The rotary kiln is the most common lime kiln design used in the kraft pulp and paper industry. Rotary lime kilns range from 8 to 13 feet in diameter, and from

**TABLE 6-1. ARSENIC EMISSION FACTORS FOR KRAFT PROCESS RECOVERY FURNACES AND
SMELT DISSOLVING TANKS**

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMton BLS ^a	Emission Factor Rating
3-07-001-04	Direct Contact Evaporator Kraft Recovery Furnace	ESP	34	D
3-07-001-10	Nondirect Contact Evaporator Kraft Recovery Furnace	ESP, ESP and Wet Scrubber	15.4	D
3-07-001-05	Smelt Dissolving Tank	Demister	7.0×10^{-1}	D

Source: References 7 and 8.

^a Emission factors are in lb of pollutant emitted per million ton of black liquor solids (BLS) burned. To convert to kg per million metric tons (kg/MMton), multiply by 0.50.

ESP = Electrostatic Precipitator.

TABLE 6-2. DISTRIBUTION OF KRAFT PULP MILLS IN THE UNITED STATES (1997)

State	Number of Mills
Alabama	14
Arizona	1
Arkansas	7
California	2
Florida	7
Georgia	12
Idaho	1
Kentucky	2
Louisiana	10
Maine	7
Maryland	1
Michigan	3
Minnesota	2
Mississippi	6
Montana	1
New Hampshire	1
New York	1
North Carolina	6
Ohio	1
Oklahoma	1
Oregon	7
Pennsylvania	3
South Carolina	6
Tennessee	2
Texas	6
Virginia	4
Washington	6
Wisconsin	4
Total	124

Source: Reference 6.

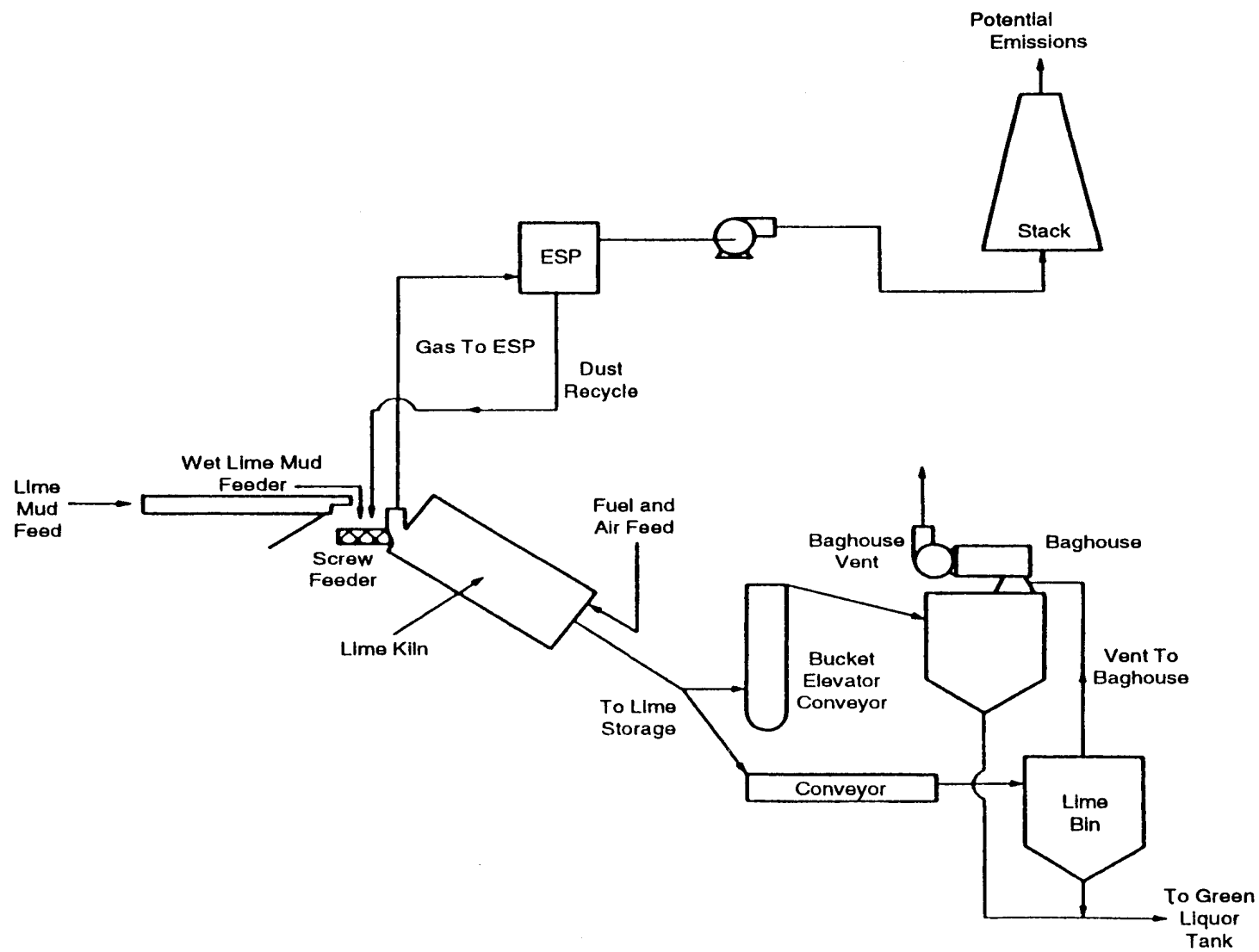


Figure 6-4. Process Flow Diagram for Lime Kiln

Source: Reference 5.

100 to 400 feet in length. Lime kilns predominantly fire natural gas, with some units firing distillate and/or residual fuel oil. Many facilities incinerate non-condensable gases (NCG) from pulping source vents in lime kilns to control total reduced sulfur (TRS) emissions. Temperatures in the kiln can range from 300 to 500°F at the upper or wet end to 2,200 to 2,400°F at the hottest part of the calcination zone near the lower or dry end.^{5,9}

Emissions of concern from lime kilns include PM, largely in the form of calcium salts. Some of the PM also contains arsenic. Emissions of arsenic from lime kilns are likely due to the arsenic content of the lime mud with some contribution from the combustion of fossil fuel (natural gas or fuel oil). The most common PM control technologies used on lime kilns are scrubbers (some ESPs are also used). Scrubbers on lime kilns use either fresh water or clean condensates from pulping sources as a scrubbing medium. Small amounts of caustic solution may be added to the scrubbing solution to scrub TRS & SO₂. Lime kiln scrubber designs include impingement, venturi, and cyclonic scrubbers.¹⁰

6.2.2 Emission Factors

Arsenic emission factors for uncontrolled and scrubber-controlled lime kilns are presented in Table 6-3.^{6,7,11}

6.2.3 Source Locations

Lime kilns are primarily located at kraft process pulp mills. See Table 6-2 in Section 6.1 for kraft pulp mill source locations reported in 1997.

6.3 Sulfite Recovery Furnaces

6.3.1 Process Description

Although not as commonplace, the acid sulfite pulp production process is similar to the kraft process except that different chemicals are used for cooking. Sulfurous acid is used in place

TABLE 6-3. ARSENIC EMISSION FACTORS FOR LIME KILNS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMton BLS ^a	Emission Factor Rating	Reference
3-07-001-06	Lime Kiln	None	4.68×10^{-7} ^b	U	11
		Scrubber	14.5	D	7,8

^a Emission factors in lb per million ton of black liquor solids generated of the mill. To convert to kg per million metric tons (kg/MMtonne), multiply by 0.5.

^b Emission factors in lb per air dry ton of pulp produced.

of a caustic solution to dissolve wood lignin. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium, or ammonium is used. Digestion occurs under high temperature and pressure, as in the kraft process, in either batch mode or continuous digesters. Following digestion and discharge of the pulp into an atmospheric blow pit or dump tank, the spent sulfite liquor, known as red liquor, may be treated and discarded, incinerated, or sent through a recovery process for recovery of heat and chemicals. Additionally, chemicals can be recovered from gaseous streams such as those from red stock washers. The cost of the soluble bases, with the exception of calcium, makes chemical recovery economically feasible.^{1,5} A simplified process schematic of magnesium-based sulfite pulping and chemical recovery is shown in Figure 6-5.

Chemical recovery in the sulfite process involves the concentration of weak red liquor in multiple effect evaporators and DCEs to strong red liquor (55 to 60 percent solids). This liquor is sprayed into a furnace and burned, producing steam for mill processes. When magnesium-based liquor is burned, magnesium oxide is recovered from the flue gas in a multicyclone. The collected magnesium oxide is then water-slaked and used as circulation liquor in a series of venturi scrubbers designed to absorb SO₂ from the flue gas to form bisulfite solution for use in the cook cycle.

Several processes for chemical recovery from sodium-base liquor are based upon the combustion of concentrated liquor in a kraft-type recovery furnace. The resultant smelt is similar in composition to that produced by combustion of kraft liquor. The commercial approaches to convert sodium-base smelt chemicals into regenerated cooking liquor include Sivola-Lurgi,

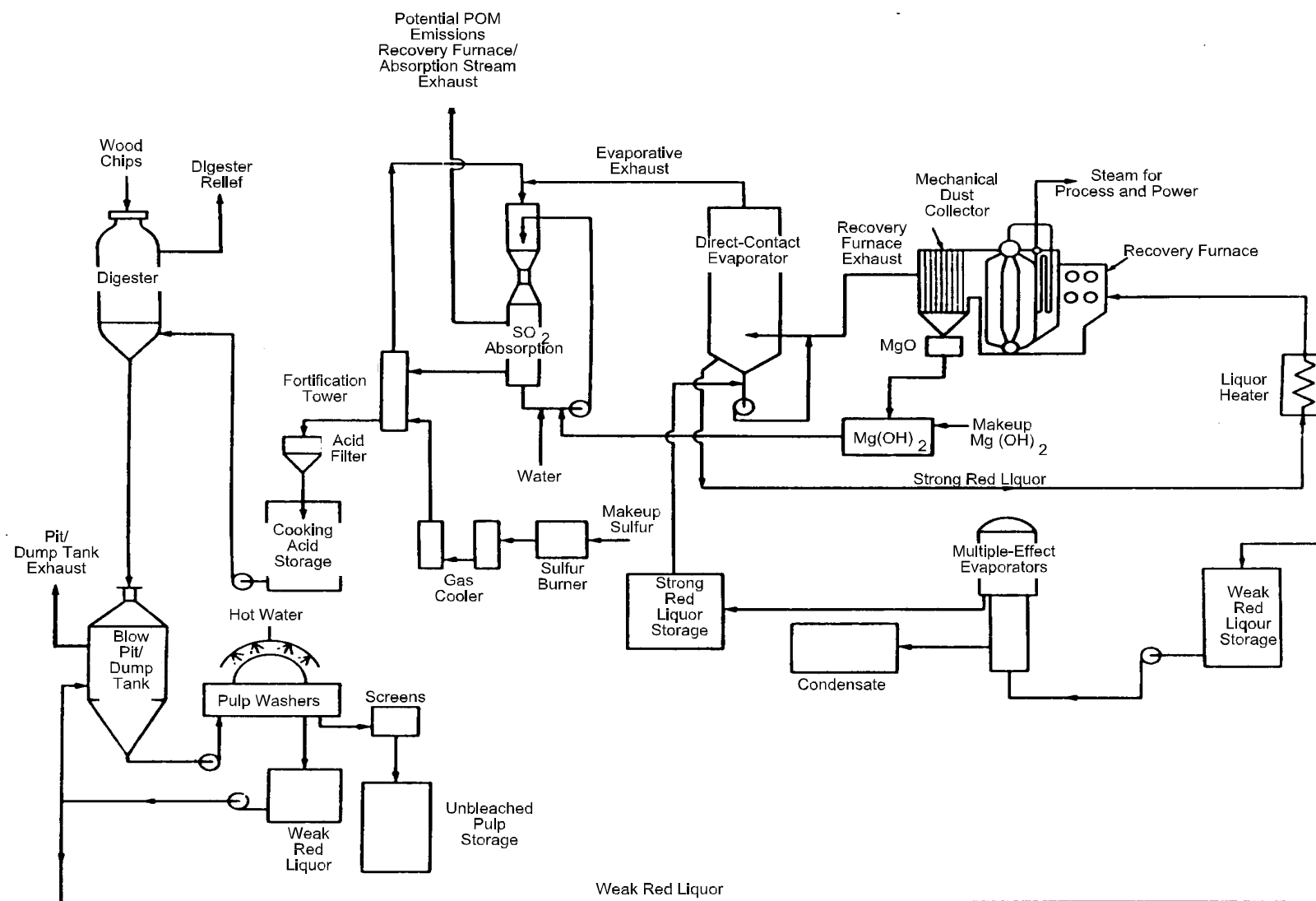


Figure 6-5. Process Diagram for Magnesium-Based Sulfite Pulping and Chemical Recovery

Source: Reference 4.

Tampella, Storm, Mead, and Rayonier.¹² Sulfite mills that do not practice chemical recovery require an acid plant to fulfill total sulfite demand. This is accomplished by rotary or spray sulfur burners equipped with heat exchangers and SO₂-absorbing scrubbers.

6.3.2 Emission Factors

As with the kraft process, arsenic exists only as a contaminant in process chemicals and in trace amounts in wood, and is, therefore, released in minute quantities. Only one emission factor was available in the literature for arsenic from an uncontrolled sulfite recovery furnace. The arsenic emission factor is presented in Table 6-4.^{7,8}

6.3.3 Source Locations

Sulfite recovery furnaces are located at sulfite process pulp mills. Table 6-5 shows the distribution of sulfite pulp mills in the United States in 1997.¹

TABLE 6-4. ARSENIC EMISSION FACTORS FOR SULFITE PROCESS
RECOVERY FURNACES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMton RLS ^a	Emission Factor Rating
3-07-002-22	Sulfite Recovery Furnace	None	3.4	D

Source: References 7 and 8.

^a Emission factors in lb pollutant per million ton of red liquor solid burned. To convert to kg per million metric tons (kg/MMtonne) multiply by 0.5.

TABLE 6-5. DISTRIBUTION OF SULFITE PULP MILLS IN THE UNITED STATES (1997)

State	Number of Mills
Alaska	1
Florida	1
Maine	1
New York	1
Pennsylvania	1
Washington	5
Wisconsin	4
Total	14

Source: Reference 6.

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SECTION 7.0

EMISSIONS OF ARSENIC AND ARSENIC COMPOUNDS FROM OTHER SOURCES

This section provides an overview of the miscellaneous sources of arsenic emissions. These sources can be divided into the following categories: Glass Manufacturing; Municipal Solid Waste Landfills; Asphalt Concrete Production; Abrasive Grain Processing; Prepared Feeds Manufacturing; Portland Cement Production; Open Burning of Scrap Tires; Grain Milling; Process Heaters; and Cotton Production and Ginning. Section 7.0 accounts for the smaller producers of arsenic emissions. Processes and associated emissions are provided, where known. Often, these sources are incomplete, therefore the reader should contact sources of interest to verify the process and control techniques employed prior to applying any emission factor presented in this section.

The reader should also note that TRI data indicate that arsenic is potentially emitted from facilities within the categories listed in Table 7-1;¹ however, specific emissions data are lacking and current literature does not indicate the origins of these emissions. Therefore, further discussion of these sources is not included in this section.

7.1 Glass Manufacturing

Commercially produced glass is classified as soda-lime, lead, fused silica, borosilicate, or 96 percent silica. Four basic operations are performed in all glass manufacturing facilities: (1) preparation of raw material, (2) melting in a furnace, (3) forming, and (4) finishing.²

The products of the industry are flat glass (SIC 3211), container glass (SIC 3221), pressed and blown glass (SIC 3229) and wool fiberglass (SIC 3296). The operations for glass

TABLE 7-1. OTHER SOURCES OF ARSENIC EMISSIONS

Source Category	Number of Sources Reported in TRI
Pharmaceutical preparations manufacturing	2
Electrometallurgical products manufacturing	1
Storage batteries manufacturing	2
Sawmills and planing mills, general	2
Petroleum refining	2
Small arms munitions manufacturing	2
Plating and polishing	1
Nonferrous rolling and drawing	1
Medicinals and botanicals manufacturing	1
Copper rolling and drawing	1
Other biological incineration	1,700

Source: Reference 1.

manufacturing are generally the same for all products except for forming, finishing and post processing.³

7.1.1 Process Description

Raw materials including silica sand, limestone, soda ash and minor ingredients are received and stored at a production facility called a batch plant. The raw materials are then transferred to a weigher and mixed for a set period of time. Cullet (recycled glass) is added to assist in the melting process. The mixture (batch) is conveyed to a batch storage bin where it is held until fed into the melting furnace on a demand basis.³

Next, these raw materials are melted in a glass melting furnace to form a homogenous liquid at approximately 2,800°F. The continuous furnaces are charged continuously or intermittently by means of automatic or manual feeders. The glass furnaces are generally of the regenerative or recuperative type fired by gas or oil with electric boosting for additional heating

and control. Production of certain low viscosity glasses such as crystal which require special production techniques may be carried out in day tanks. The melted glass is held at the molten state until it reaches a desired red state of homogeneity and is then cooled to about 2,200°F or less for delivery to the forming stage of the process.³

Finally, the molten material is drawn from the furnace and worked on forming machines by a variety of methods, including pressing, blowing, drawing, or rolling to produce the desired product.

The end product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass). Any damaged or undesirable glass is transferred back to the batch plant to be used as cullet.

7.1.2 Emission Control Techniques

Baghouses, venturi scrubbers, and ESPs are currently used in the various processes associated with the glass manufacturing industry. Therefore, an overall control efficiency of at least 90 percent is expected and should be applied to emissions estimated using the factor in Table 7-2.⁴

7.1.3 Emissions

Air emissions from glass manufacturing occur in three areas: raw material blending and transport, melting, and forming and finishing. Fugitive dust is produced by the blending and transport process. In most cases, fabric filters are used on silos and the transport system to confine the particulate emissions. Arsenic emissions from the raw material preparation and forming and finishing operations are generally considered to be negligible.

The glass melting furnace is the principal source of arsenic emissions from a glass plant. The composition and rate of emissions from glass melting furnaces vary considerably, depending

TABLE 7-2. ARSENIC EMISSION FACTOR FOR GLASS MANUFACTURING

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Rating
3-05-014	Regenerative-type Furnaces	None	5.00x10 ⁻¹	U

Source: Reference 4.

^a To convert to kg per metric ton (kg/tonne) multiply by 0.5.

upon the composition of glass being produced and, to a lesser extent, upon the design and operating characteristics of the furnace. Emissions consist primarily of products of combustion and entrained PM. One emission factor for uncontrolled arsenic emission from glass manufacturing was found and is presented in Table 7-2. Additional sources of information include Glass Manufacturing Plants - Background information for Proposed Standards (EPA-450/3-79-005a), Summary Report on Emissions from the Glass Manufacturing Industry (EPA-600/2-79-101), and The Handbook of Glass Manufacture, 3rd Edition Volume II.

7.2 Municipal Solid Waste Landfills

A municipal solid waste (MSW) landfill unit is a discrete area of land or an excavation that receives household waste, but is not a land application unit (i.e., for receiving sewage sludge). An MSW landfill unit may also receive other types of wastes, such as commercial solid waste, nonhazardous sludge, and industrial solid waste. Arsenic emissions from MSW landfills are expected to originate from the non-household sources of MSW.

7.2.1 Process Description

There are three major designs for municipal landfills: the area method, the trench method, and the ramp method.⁵ They all utilize a three-step process, which includes spreading the waste, compacting the waste, and covering the waste with soil. The area fill method involves placing waste on the ground surface or landfill liner, spreading it in layers, and compacting it with heavy equipment. A daily soil cover is spread over the compacted waste. The trench method entails excavating trenches designed to receive a day's worth of waste. The soil from the

excavation is often used for cover material and wind breaks. The ramp method is typically employed on sloping land, where waste is spread and compacted in a manner similar to the area method; however, the cover material obtained is generally from the front of the working face of the filling operation. The trench and ramp methods are not commonly used, and are not the preferred methods when liners and leachate collection systems are utilized or required by law.

Modern landfill design often incorporates liners constructed of soil (e.g., recompacted clay) or synthetics (e.g., high density polyethylene) or both to provide an impermeable barrier to leachate (i.e., water that has passed through the landfill) and gas migration from the landfill.

7.2.2 Emission Control Techniques

Landfill gas collection systems are either active or passive systems. Active collection systems provide a pressure gradient in order to extract landfill gas by use of mechanical blowers or compressors. Passive systems allow the natural pressure gradient created by the increase in landfill pressure from landfill gas generation to mobilize the gas for collection.

Landfill gas control and treatment options include (1) combustion of the landfill gas, and (2) purification of the landfill gas. Combustion techniques include techniques that do not recover energy (e.g., flares and thermal incinerators) and techniques that recover energy and generate electricity from the combustion of the landfill gas (e.g., gas turbines and internal combustion engines). Boilers can also be employed to recover energy from landfill gas in the form of steam. Flares involve an open combustion process that requires oxygen for combustion; the flares can be open or enclosed. Thermal incinerators heat an organic chemical to a high enough temperature in the presence of sufficient oxygen to oxidize the chemical to CO₂ and water. Purification techniques can also be used to process raw landfill gas to pipeline quality natural gas by using adsorption, absorption, and membranes.⁵

7.2.3 Emission Factors

During the development of this document, only one test report was acquired that summarized arsenic emissions from a landfill equipped with waste gas flares. An emission factor developed from these data is presented in Table 7-3.⁶

7.2.4 Source Locations

MSW management in the United States is dominated by disposal in landfills. Approximately 67 percent of solid waste is landfilled, 16 percent is incinerated, and 17 percent is recycled or composted. There were an estimated 5,345 active MSW landfills in the United States in 1992. In 1990, active landfills were receiving an estimated 130 million tons of waste annually, with 55 to 60 percent reported as household waste and 35 to 45 percent reported as commercial waste.⁵

7.3 Asphalt Concrete

7.3.1 Process Description

To produce hot-mix asphalt (also referred to as asphalt concrete), aggregate, which is composed of gravel, sand, and mineral filler, is heated to eliminate moisture and then mixed with hot asphalt cement. The resulting hot mixture is pliable and can be compacted and smoothed. When it cools and hardens, hot-mix asphalt provides a waterproof and durable pavement for roads, driveways, parking lots, and runways.

There are three types of hot-mix asphalt plants operating in the United States: batch-mix, continuous-mix, and drum-mix. Batch-mix and continuous-mix plants separate the aggregate drying process from the mixing of aggregate with asphalt cement. Drum-mix plants combine these two processes. Production capacities for all three types of plants range from 40 to 600 tons

TABLE 7-3. ARSENIC EMISSION FACTOR FOR LANDFILL PROCESS GAS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMBtu ^a	Emission Factor Range in lb/MMBtu ^a	Emission Factor Rating
1-02-007-99	Process Gas: Landfills	None	4.32x10 ⁻⁶	4.19x10 ⁻⁶ - 4.42x10 ⁻⁶	U

Source: Reference 6.

^a Emission factor is expressed in lb of pollutant emitted per MMBtu of heat input. To convert to kg per Mega Joule (kg/MJ), multiply by 0.43.

of hot mix per hour. Almost all plants in operation are of either the batch-mix or drum-mix type. Less than 0.5 percent of operating hot-mix plants are of the continuous-mix design.⁷

Aggregate, the basic raw material of hot-mix asphalt, consists of any hard, inert mineral material. Aggregate typically comprises between 90 and 95 percent by weight of the asphalt mixture. Because aggregate provides most of the load-bearing properties of a pavement, the performance of the pavement depends on selection of the proper aggregate.

Asphalt cement is used as the binding agent for aggregate. It prevents moisture from penetrating the aggregate and acts as a cushioning agent. Typically, asphalt cement constitutes 4 to 6 percent by weight of a hot-mix asphalt mixture.⁸ Asphalt cement is obtained from the distillation of crude oil. It is classified into grades under one of three systems. The most commonly used system classifies asphalt cement based on its viscosity at 140°F (60°C). The more viscous the asphalt cement, the higher its numerical rating.

The asphalt cement grade selected for different hot-mix asphalts depends on the type of pavement, climate, and type and amount of traffic expected. Generally, asphalt pavement bearing heavy traffic in warm climates requires a harder asphalt cement than pavement subject to either light traffic or cold climate conditions.

Another material used to a greater extent in the production of new or virgin hot-mix asphalt is recycled asphalt pavement (RAP), which is pavement material that has been removed from existing roadways. RAP is now used by virtually all companies in their hot-mix asphalt mixtures. The Surface Transportation Assistance Act of 1982 encourages recycling by providing a 5-percent increase in Federal funds to State agencies that recycle asphalt pavement. Rarely does the RAP comprise more than 60 percent by weight of the new asphalt mixture. Twenty-five percent RAP is typical in batch plants, and 40 to 50 percent RAP mixtures are typical in drum-mix plants.⁸

The primary processes of a typical batch-mix hot-mix asphalt facility are illustrated in Figure 7-1.⁷ The moisture content of the stockpiled aggregate at the plant usually ranges from

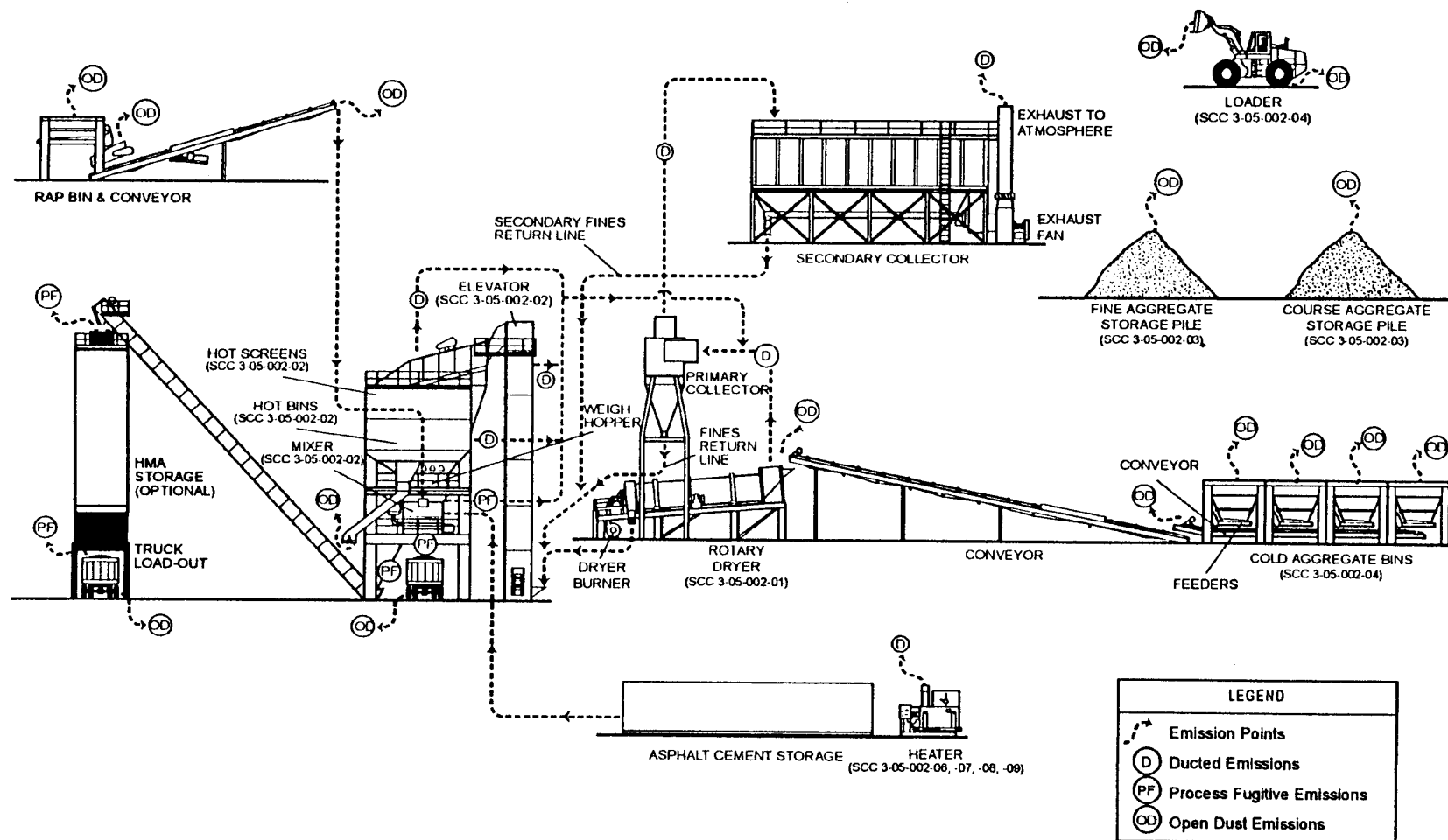


Figure 7-1. General Process Flow Diagram for Batch-Mix Asphalt Paving Plants

Source: Reference 7.

3 to 5 percent. The moisture content of recycled hot-mix asphalt typically ranges from 2 to 3 percent. The different sizes of aggregate are typically transported by front-end loader to separate cold-feed bins and metered onto a feeder conveyor belt through gates at the bottom of the bins. The aggregate is screened before it is fed to the dryer to keep oversize material out of the mix.

The screened aggregate is then fed to a rotating dryer with a burner at its lower (discharge) end that is fired with fuel oil, natural gas, or propane. In the production of hot-mix asphalt, the majority of arsenic emissions can be expected from the rotating dryer. The dryer removes moisture from the aggregate and heats the aggregate to the proper mix temperature. Arsenic emissions occur primarily from fuel combustion. Aggregate temperature at the discharge end of the dryer is about 300°F. The amount of aggregate that a dryer can heat depends on the size of the drum, the size of the burner, and the moisture content of the aggregate. As the amount of moisture to be removed from the aggregate increases, the effective production capacity of the dryer decreases.

Vibrating screens segregate the heated aggregate into bins according to size. A weigh hopper meters the desired amount of the various sizes of aggregate into a pugmill mixer. The pugmill typically mixes the aggregate for 15 seconds before hot asphalt cement from a heated tank is sprayed into the pugmill. The pugmill thoroughly mixes the aggregate and hot asphalt cement for 25 to 60 seconds. The finished hot-mix asphalt is either loaded directly into trucks or held in insulated and/or heated storage silos. Depending on the production specifications, the temperature of the hot-mix asphalt product mix can range from 225 to 350°F at the end of the production process.

Continuous-mix plants are very similar in configuration to batch plants. Asphalt cement is continuously added to the aggregate at the inlet of the mixer. The aggregate and asphalt cement are mixed by the action of rotating paddles while being conveyed through the mixer. An adjustable dam at the outlet end of the mixer regulates the mixing time and also provides some surge capacity. The finished mix is transported by a conveyor belt to either a storage silo or surge bin.⁸

Drum-mix plants dry the aggregate and mix it with the asphalt cement in the same drum, eliminating the need for the extra conveyor belt, hot bins and screens, weigh hopper, and pugmill of batch-mix plants. The drum of a drum-mix plant is much like the dryer of a batch plant, but it typically has more flights than do batch dryers to increase veiling of the aggregate and to improve overall heat transfer. The burner in a drum-mix plant emits a much bushier flame than does the burner in a batch plant. The bushier flame is designed to provide earlier and greater exposure of the virgin aggregate to the heat of the flame. This design also protects the asphalt cement, which is injected away from the direct heat of the flame.⁸

Initially, drum-mix plants were designed to be parallel-flow, as depicted in Figure 7-2. Recently, the counterflow drum-mix plant design shown in Figure 7-3 has become popular.⁷ The parallel flow drum-mix process is a continuous mixing type process using proportioning cold feed controls for the process materials. Aggregate, which has been proportioned by gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregates and the combustion products move toward the other end of the drum in parallel. Liquid asphalt cement flow is controlled by a variable flow pump that is electronically linked to the virgin aggregate and RAP weigh scales. The asphalt cement is introduced in the mixing zone midway down the drum in a lower temperature zone along with any RAP and PM from collectors. The mixture is discharged at the end of the drum and conveyed to a surge bin or storage silos. The exhaust gases also exit the end of the drum and pass on to the collection system.⁷

In a counterflow drum-mix plant, the material flow in the drum is opposite or counterflow to the direction of the exhaust gases. In addition, the liquid asphalt cement mixing zone is located behind the burner flame zone so as to remove the materials from direct contact with hot exhaust gases. Liquid asphalt cement flow is still controlled by a variable flow pump and is injected into the mixing zone along with any RAP and PM from primary and secondary collectors.⁷

Of the 3,600 active hot-mix asphalt plants in the United States, approximately 2,300 are batch-mix plants, 1,000 are parallel-flow drum-mix plants, and 300 are counterflow drum-mix plants. About 85 percent of plants being constructed today are of the counterflow drum-mix

Source: Reference 7.

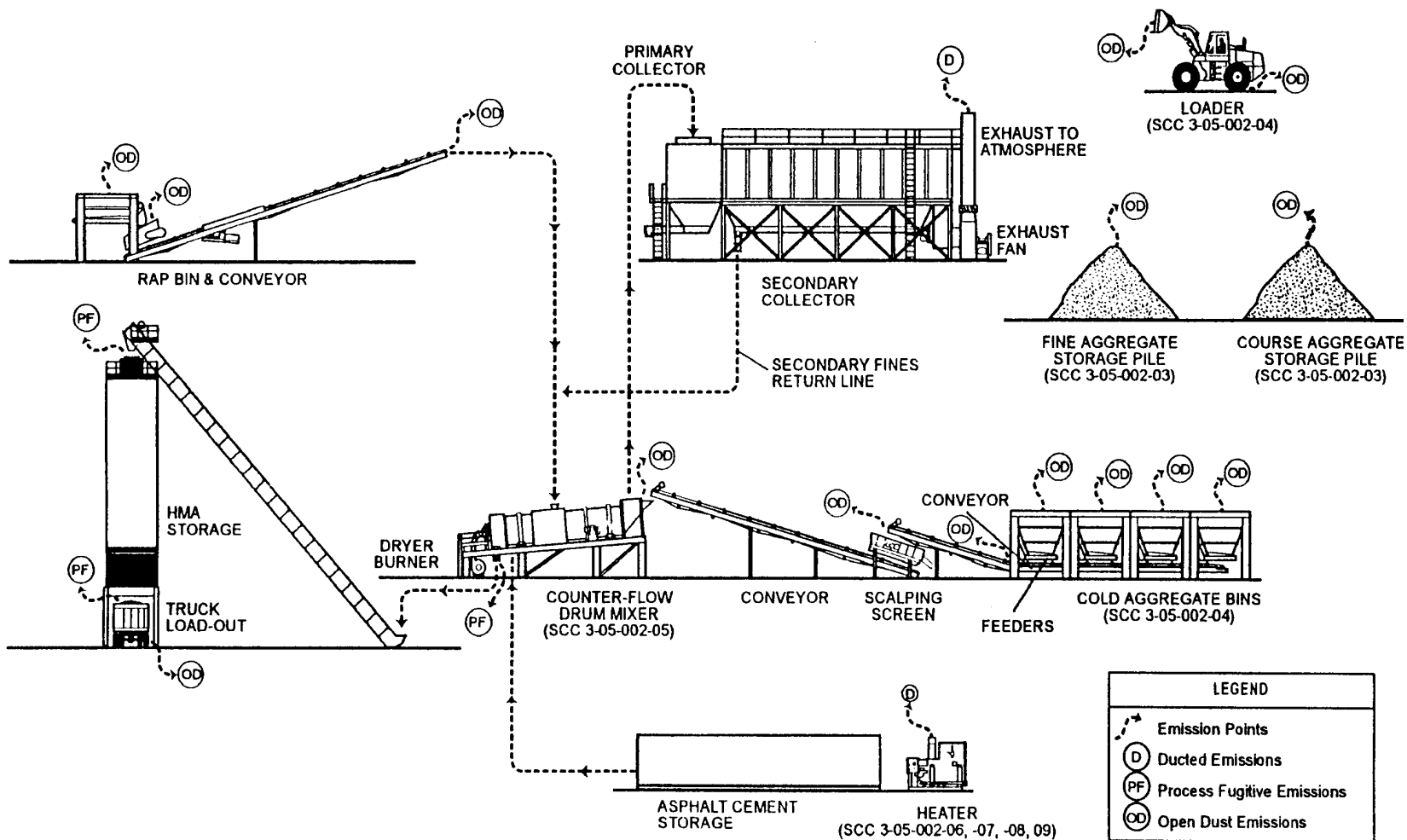


Figure 7-3. General Process Flow Diagram for Counterflow Drum-Mix Asphalt Paving Plants

Source: Reference 7.

design; batch-mix plants and parallel-flow drum-mix plants account for 10 percent and 5 percent respectively.⁷

7.3.2 Emission Control Techniques

Emissions of arsenic from hot-mix asphalt plants most likely occur because of fuel combustion in the aggregate rotary dryers, but some emissions from the aggregate during the drying process are possible. These emissions are most often controlled by wet scrubbers or baghouses.⁷

7.3.3 Emission Factors

Emissions from hot-mix asphalt plants were reexamined recently for the purpose of updating AP-42. Representative batch-mix and drum-mix plants (both parallel and counterflow) were selected for testing. Emissions from hot-oil heaters used to warm stored asphalt concrete were also evaluated. Arsenic emissions from hot-mix plants can result from fuel combustion, aggregate mixing and drying, and asphalt heating. The only arsenic emissions found from these tests were from the drying process. These arsenic emission factors and two from other source testing are provided in Table 7-4.^{7,9,10}

7.3.4 Source Locations

In 1983, there were approximately 2,150 companies operating an estimated 4,500 hot-mix asphalt plants in the United States.⁸ More recently, the number has fallen to about 3,600 plants.⁷ Approximately 40 percent of these companies operate only a single plant. Plants are usually located near the job site, so they are concentrated in areas with an extensive highway and road network.⁸ Additional information on the location of individual hot-mix asphalt facilities can be obtained by contacting the National Asphalt Pavement Association in College Park, Maryland.

TABLE 7-4. ARSENIC EMISSION FACTORS FROM ASPHALT CONCRETE PRODUCTION

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Rating	Reference
3-05-002-01	Rotary Dryer: Conventional Plant	FF	6.60×10^{-7}	E	7
		Multiple Cyclone without Fly Ash Reinjection, FF	3.53×10^{-7}	U	9
3-05-002-05	Drum Dryer: Hot Asphalt Plants	None	2.50×10^{-7}	U	10
		FF	1.10×10^{-6} ^b	D	7

^a Emission factors in lb of pollutant emitted per ton of asphalt concrete produced. To convert to kilograms per metric ton (kg/tonne) multiply by 0.5.

^b Feed material includes RAP.

7.4 Abrasive Grain Processing

Abrasive grain manufacturers produce materials for use by bonded and coated abrasive product manufacturers to make abrasive products.

7.4.1 Process Description

The most commonly used abrasive materials for abrasive grain manufacturing are silicon carbide and aluminum oxides. These synthetic materials account for as much as 80 to 90 percent of the abrasive grains produced domestically. Other materials used for abrasive grains are cubic boron nitride (CBN), synthetic diamonds, and several naturally occurring minerals such as garnet and emery. The use of garnet as an abrasive grain is decreasing. CBN is used for machining the hardest steels to precise forms and finishes. The largest application of synthetic diamonds has been in wheels for grinding carbides and ceramics. Natural diamonds are used primarily in diamond-tipped drill bits and saw blades for cutting or shaping rock, concrete, grinding wheels, glass, quartz, gems, and high-speed tool steels. Other naturally occurring abrasive materials (including garnet, emery, silica sand, and quartz) are used in finishing wood, leather, rubber, plastics, glass, and softer metals.¹¹

Silicon carbide is manufactured in a resistance arc furnace charged with a mixture of approximately 60 percent silica sand and 40 percent finely ground petroleum coke. A small amount of sawdust is added to the mix to increase its porosity so that the CO formed during the process can escape freely. Common salt is added to the mix to promote the carbon-silicon reaction and remove impurities in the sand and coke. During the heating period, the furnace core reaches approximately 4,000°F, at which point a large portion of the load crystallizes. At the end of the run, the furnace contains a core of loosely knit silicon carbide crystals surrounded by unreacted or partially reacted raw materials. The silicon carbide crystals are removed to begin processing into abrasive grains.

Fused aluminum oxide is produced in pot-type electric arc furnaces with capacities of several tons. Before processing, bauxite, the crude raw material, is calcined at about 1,740°F to

remove both free and combined water. The bauxite is then mixed with ground coke (about 3 percent) and iron borings (about 2 percent). An electric current is applied and the intense heat, on the order of 3,700°F, melts the bauxite and reduces the impurities that settle to the bottom of the furnace. As the fusion process continues, more bauxite mixture is added until the furnace is full. The furnace is then emptied and the outer impure layer is stripped off. The core of aluminum oxide is then removed to be processed into abrasive grains.

CBN is synthesized in crystal form from hexagonal boron nitride, which is composed of atoms of boron and nitrogen. The hexagonal boron nitride is combined with a catalyst such as metallic lithium at temperatures in the range of 3,000°F and pressures of up to 1,000,000 pounds per square inch (psi).

Synthetic diamond is manufactured by subjecting graphite in the presence of a metal catalyst to pressures in the range of 808,000 to 1,900,000 psi at temperatures in the range of 2,500 to 4,500°F.

Figure 7-4 presents a process flow diagram for abrasive grain processing.¹¹ Abrasive grains for both bonded and coated abrasive products are made by graded crushing and close sizing of either natural or synthetic abrasives. Raw abrasive materials first are crushed by primary crushers and then reduced by jaw crushers to manageable size, approximately 0.75 inches. Final crushing is usually accomplished with roll crushers that break up the small pieces into a usable range of sizes. The crushed abrasive grains are then separated into specific grade sizes by passing them over a series of screens. If necessary, the grains are washed in classifiers to remove slimes, dried, and passed through magnetic separators to remove iron-bearing material before they are again closely sized on screens. This careful sizing is necessary to prevent contamination of grades by coarser grains. Sizes finer than 250 grit are separated by hydraulic flotation and sedimentation or by air classification.

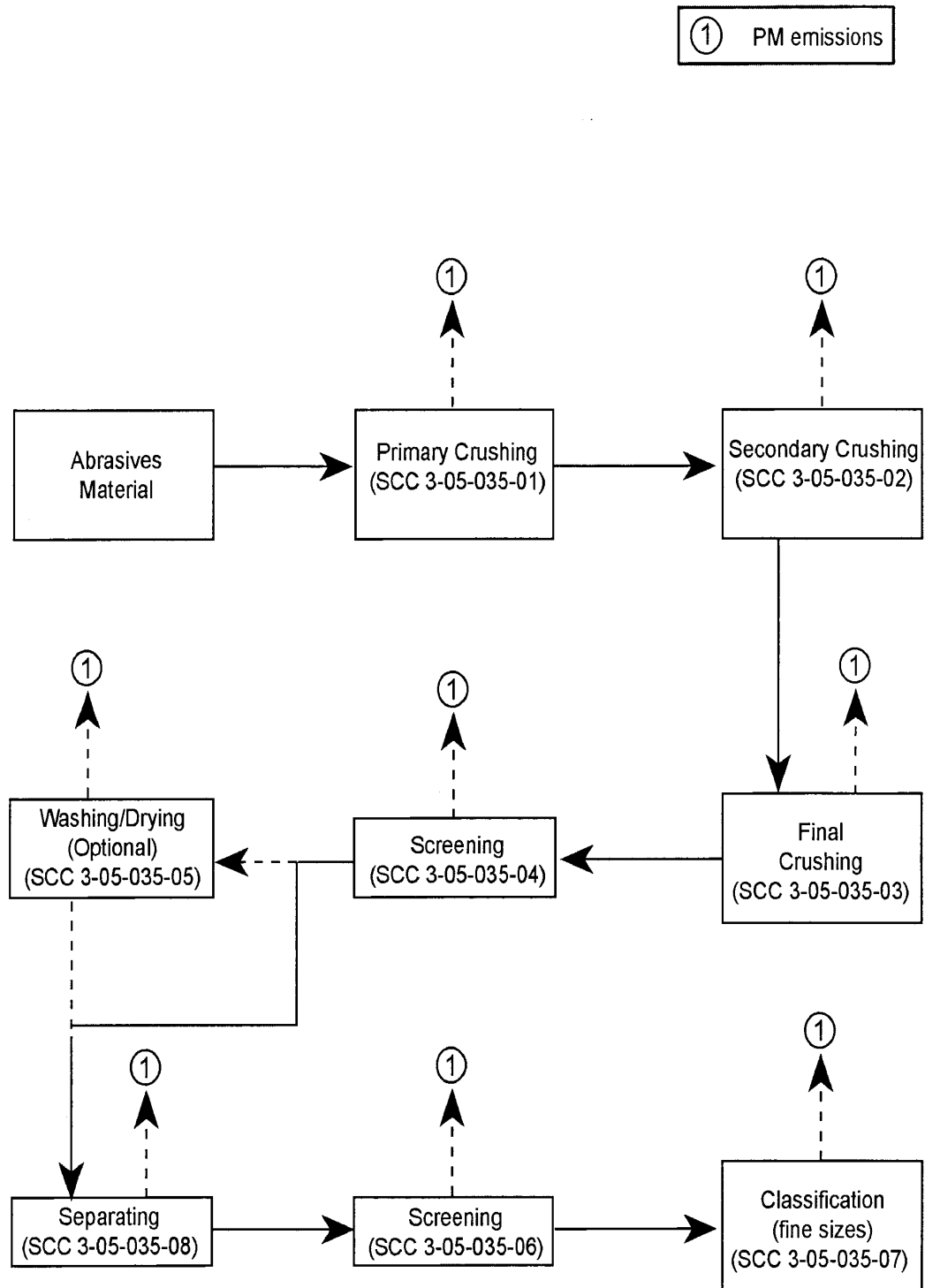


Figure 7-4. Flow Diagram for Abrasive Grain Processes

Source: Reference 11.

7.4.2 Emission Control Techniques

Fabric filters preceded by cyclones are used at some facilities to control PM emissions from abrasive grain production. This configuration of control devices can attain controlled emission concentrations of 37 micrograms per dry standard cubic meter (0.02 grains per dry standard cubic foot) and control efficiencies in excess of 99.9 percent. Little other information is available on the types of controls used by the abrasives industry to control PM emissions. However, it is assumed that other conventional devices such as scrubbers and electrostatic precipitators can be used to control PM emissions from abrasives grain and products manufacturing.¹¹

7.4.3 Emission Factors

Little information is available on emissions from the manufacture of abrasive grains and products.

Emissions from the production of synthetic abrasive grains, such as aluminum oxide and silicon carbide, are likely to consist primarily of PM, PM₁₀, and CO from the furnaces. Aluminum oxide processing takes place in an electric arc furnace and involves temperatures up to 4,710°F with raw materials of bauxite ore, silica, coke, iron borings, and a variety of minerals that include chromium oxide, cryolite, pyrite, and silane. This processing is likely to emit fluorides, sulfides, and metal constituents of the feed material.

The primary emissions from abrasive grain processing consist of PM and PM₁₀ from the crushing, screening, classifying, and drying operations. PM is also emitted from materials handling and transfer operations. Table 7-5 presents an arsenic emission factor developed from the results of a metals analysis conducted on a rotary dryer controlled by a wet scrubber in an abrasive grain processing facility.¹¹

TABLE 7-5. ARSENIC EMISSION FACTOR FOR ABRASIVE GRAIN PROCESSING

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Rating
3-05-035-05	Rotary Dryer: Sand Blasting Grit	Wet Scrubber	2.40x10 ⁻⁴	E

Source: Reference 11.

^aEmission factor is expressed in lb of pollutant emitted per ton of grit fed into dryer. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

7.4.4 Source Locations

The abrasives industry is composed of approximately 400 companies throughout the United States engaged in abrasive grain manufacturing, bonded abrasive product manufacturing, and coated abrasive product manufacturing.¹¹ However, the majority of the arsenic emissions from abrasive grain manufacturing come from the primary silicon carbide and aluminum oxide production facilities, and less than ten of these facilities are currently in operation in the United States.^{12,13} The locations of these facilities are shown in Table 7-6.

7.5 Portland Cement Production

Most of the hydraulic cement produced in the United States is Portland cement--a mixture primarily composed of calcium silicates, aluminates, and aluminoferrites. There are four primary components in Portland cement manufacturing: raw materials handling, kiln feed preparation, pyroprocessing, and finished cement grinding. Pyroprocessing, the fuel intensive process accomplished in cement kilns, has been identified as a potential source of arsenic emissions and constitutes the primary focus of this chapter.¹⁴

TABLE 7-6. 1995 U.S. PRIMARY ABRASIVE GRAIN MANUFACTURER LOCATIONS
BY STATE

State	No. of Facilities
Illinois	1
Massachusetts	2
New York	3

Source: References 12,13.

7.5.1 Process Description

Figure 7-5 presents a basic flow diagram of the Portland cement manufacturing process. The process can be divided into four major steps: raw material acquisition and handling, kiln feed preparation, pyroprocessing, and finished cement grinding.¹⁴

The initial step in the production of Portland cement manufacturing is raw materials acquisition. Calcium, which is the element of highest concentration in Portland cement, is obtained from a variety of calcareous raw materials, including limestone, chalk, marl, sea shells, aragonite, and an impure limestone known as “natural cement rock.” The other raw materials--silicon, aluminum, and iron--are obtained from ores and minerals such as sand, shale, clay, and iron ore. Arsenic is expected to be present in the ores and minerals extracted from the earth. The only potential source of arsenic emissions from raw material acquisition would be due to wind-blown particulate-containing arsenic from the quarry operations. Arsenic emissions are expected to be negligible from these initial steps in Portland cement production.¹⁴

The second step involves preparation of the raw materials for pyroprocessing (thermal treatment). Raw material preparation includes a variety of blending and sizing operations designed to provide a feed with appropriate chemical and physical properties. The raw material processing differs for wet processes and dry processes. At facilities where the dry process is used, the moisture content in the raw material, which can range from less than 1 percent to

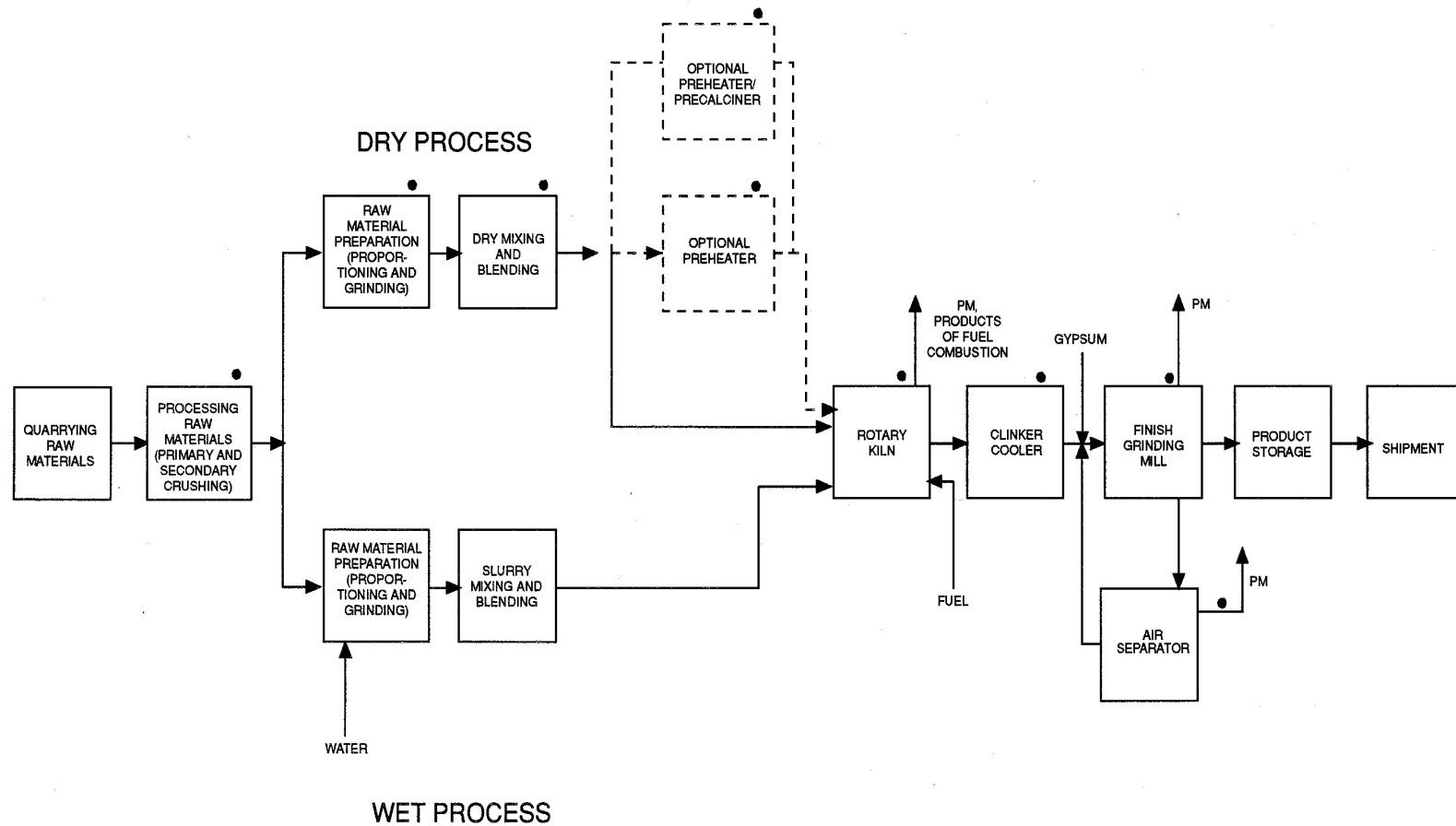


Figure 7-5. Process Flow Diagram Of Portland Cement Manufacturing Process

Source: Reference 15.

greater than 50 percent, is reduced to less than 1 percent. Arsenic emissions can occur during this drying process, but are anticipated to be very low because the drying temperature is much below the boiling point of arsenic. At some facilities, heat for drying is provided by the exhaust gases from the pyroprocessor. At facilities where the wet process is used, water is added to the raw material during the grinding step, thereby producing a pumpable slurry containing approximately 65 percent solids.¹⁴

Pyroprocessing of the raw material is carried out in the kiln, which is the heart of the Portland cement manufacturing process. During pyroprocessing, the raw material is transformed into clinkers, which are gray, glass-hard, spherically shaped nodules that range from 0.125 to 2.0 in. in diameter. The chemical reactions and physical processes that take place during pyroprocessing include the following:

1. Evaporation of uncombined water from raw materials as material temperature increases to 212°F.
2. Dehydration as the material temperature increases from 212°F to approximately 800°F to form the oxides of silicon, aluminum, and iron.
3. Calcination, during which carbon dioxide (CO₂) is evolved between 1,650°F and 1,800°F to form calcium oxide.
4. Reaction of the oxides in the burning zone of the rotary kiln to form cement clinker at temperatures of about 2,750°F.¹⁴

The rotary kiln is a long, cylindrical, slightly inclined, refractory-lined furnace. The raw material mix is introduced into the kiln at the elevated end, and the combustion fuels are usually introduced into the kiln at the lower end in a countercurrent manner. The rotary motion of the kiln transports the raw material from the elevated end to the lower end. A combination of fuels such as coal, petroleum coke, or natural gas is used to provide energy for calcination. Occasionally, oil, waste plastics, waste solvents, or used oil are used although the use of waste solvents is becoming less common. Trace amounts of arsenic are naturally present in coal and oil. The use of other materials such as scrap tires is becoming more common.¹⁶

Combustion of fuel during the pyroprocessing step contributes to potential arsenic emissions. Arsenic may also be present in the waste-derived fuel mentioned above. Most of the arsenic that is volatilized in the hot end of the kiln is expected to condense onto PM upon cooling and is either removed in the downstream equipment, such as the APCD, or removed in the bypass gases or the preheater.¹⁴

Pyroprocessing can be carried out using one of five different processes: wet, semi-dry, dry, dry with a preheater, and dry with a preheater/precalciner. These processes essentially accomplish the same physical and chemical steps described above. The last step in the pyroprocessing is the cooling of the clinker. This step recoups up to 30 percent of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment. Finally, after the cement clinker is cooled, a sequence of blending and grinding operations is carried out to transform the clinker into finished Portland cement.¹⁴

7.5.2 Emission Control Techniques

With the exception of the pyroprocessing operations, the emission sources in the Portland cement industry can be classified as either process emissions or fugitive emissions. The primary pollutant resulting from the fugitive sources is PM, which contains a fraction of arsenic. The control measures used for these fugitive dust sources are comparable to those used throughout the mineral products industries.

Process fugitive emission sources include materials handling and transfer, raw milling operations in dry process facilities, and finish milling operations. Typically, particulate emissions from these processes are captured by a ventilation system vented to fabric filters. Because the dust from these units is returned to the process, they are considered to be process units as well as air pollution control devices. The industry uses shaker, reverse air, and pulse jet filters, as well as some cartridge units, but most newer facilities use pulse jet filters. For process fugitive operations, the different systems are reported to achieve typical outlet PM loadings of 0.02 grains per actual cubic foot (gr/acf).¹⁷ Because the arsenic is in particle form, it is expected

that these control devices will have a positive effect on reducing arsenic emissions; however, these reductions may not be equivalent to those achieved for overall particulate reduction, since arsenic is likely to occur in the smaller size range of particle size distribution.

In the pyroprocessing units, PM emissions are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and ESPs. The reverse air fabric filters and ESPs typically used to control kiln exhausts are reported to achieve outlet PM loadings of 0.02 gr/acf. Clinker cooler systems are controlled most frequently with pulse jet or pulse plenum fabric filters. A few gravel bed filters have been used on clinker coolers.¹⁴

7.5.3 Emission Factors

The principal source of arsenic emissions is expected to be from the kiln. The majority of the arsenic input from the raw materials and fuels is incorporated into the clinker. Arsenic volatilized from the kiln is either removed in the bypass gases, the preheater, or the APCD. Small quantities of emissions would be expected during raw materials processing and mixing in the form of fugitive dust containing naturally occurring quantities of arsenic compounds in raw materials.

Processing steps that occur after the calcining process in the kiln would be expected to be a much smaller source of emissions than the kiln. Emissions resulting from all processing steps include particulate matter. Additionally, emissions from the pyroprocessing step include other products of fuel combustion such as sulfur dioxide (SO₂), nitrogen oxides (NO_x), carbon dioxide (CO₂), and carbon monoxide (CO). Carbon dioxide from the calcination of limestone will also be present in the flue gas.

Arsenic emissions data for Portland cement kilns with various process, fuel, and control configurations were compiled by the U.S. EPA's Office of Solid Waste in 1994.^{15a} Testing was conducted at 35 Portland cement kilns to certify compliance with the BIF Rule. Emission factors developed from the study for dry process kilns and differentiated by fuel and waste type are presented in Table 7-7.¹⁸ Table 7-8 presents emission factors for various kiln types.¹⁸

TABLE 7-7. ARSENIC EMISSION FACTORS FOR DRY PROCESS PORTLAND CEMENT KILNS BY FUEL AND WASTE TYPE

SCC Number	Fuel Type	Waste Type	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Rating
3-05-006-06	Coal	Solid/Liquid Hazardous Waste	ESP	1.27x10 ⁻⁴	D
		None	Quench Column/FF	1.22x10 ⁻⁵	D
		Solid/Liquid Hazardous Waste	Quench Column/FF	1.21x10 ⁻⁵	D
		Solid/Liquid Hazardous Waste	FF	1.87x10 ⁻⁶	D
3-05-006-06	Coke	Liquid Hazardous Waste	Multiple Cyclone/FF	1.18x10 ⁻⁵	D

Source: Reference 18.

^a Emission factor is expressed in lb of pollutant emitted per ton of clinker produced. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

ESP = Electrostatic Precipitator.

FF = Fabric Filter.

Additional emission factor data may be available from databases developed by trade associations or industry groups.¹⁹

7.5.4 Source Locations

The Portland cement manufacturing industry is dispersed geographically throughout the United States. Thirty-six states have at least one facility. As of 1996, there were 109 operating Portland cement plants in the United States, operating 202 kilns with a total annual clinker capacity of approximately 80 million tons. Table 7-9 presents the name of each Portland cement plant and their kiln types and capacities as reported in 1996.²⁰

TABLE 7-8. ARSENIC EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING FACILITIES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton ^a clinker	Emission Factor Rating
3-05-006-06	Dry Process Kilns	FF	1.20x10 ⁻⁵	D
		ESP	1.30x10 ⁻⁵	E
3-05-006-22	Dry Process Preheater Kilns	FF	1.20x10 ⁻⁵	D
		ESP	1.30x10 ⁻⁵	E
3-05-006-23	Dry Process Preheater/ Precalciner Kiln	FF	1.20x10 ⁻⁵	D
		ESP	1.30x10 ⁻⁵	E
3-05-007-06	Wet Process Kilns	FF	1.20x10 ⁻⁵	D
		ESP	1.30x10 ⁻⁵	E

Source: Reference 14.

^a To convert to kg per metric ton (kg/tonne), multiply by 0.5.

ESP = Electrostatic Precipitator.

FF = Fabric Filter.

TABLE 7-9. PORTLAND CEMENT PRODUCTION FACILITIES (1995)

Company	Location	No./type of kiln	Clinker Capacity (tons/yr)
<u>Alabama</u>			
Blue Circle, Inc.	Calera, AL	2-dry	594
Holnam, Inc.	Theodore, AL	1-dry	1,438
Lehigh Portland Cement	Leeds, AL	1-dry	700
Medusa Cement Co.	Demopolis, AL	1-dry	809
National Cement Co. of Alabama	Ragland, AL	1-dry	944
<u>Arizona</u>			
Ash Grove Cement Co.	Foreman, AZ	3-wet	883
California Portland Cement	Rillito, AZ	4-dry	1,150
Phoenix Cement Co.	Clarkdale, AZ	3-dry	630
<u>California</u>			
Calaveras Cement Co.	Redding, CA	1-dry	649
Calaveras Cement Co.	Tehachapi, CA	1-dry	900
California Portland Cement	Colton, CA	2-dry	748
California Portland Cement	Mojave, CA	1-dry	1,239
Kaiser Cement Corp.	Cupertino, CA	1-dry	1,603
Mitsubishi Cement Corp.	Lucerne Valley, CA	1-dry	1,702
National Cement Co. of California	Lebec, CA	1-dry	647
Riverside Cement Co.	Oro Grande, CA	7-dry	1,177
Riverside Cement Co.	Riverside, CA	2-dry	110
RMC Lonestar	Davenport, CA	1-dry	799
Southdown, Inc.	Victorville, CA	2-dry	1,530
<u>Colorado</u>			
Holnam, Inc.	Florence, CO	3-wet	837
Holnam, Inc.	Fort Collins, CO	1-dry	496
Southdown, Inc.	Lyons, CO	1-dry	430
<u>Florida</u>			
Florida Crushed Stone	Brooksville, FL	1-dry	602
Pennsuco Cement Co.	Medley, FL	2-wet	953
Rinker Portland Cement Corp.	Miami, FL	2-wet	543
Southdown, Inc.	Brocksville, FL	2-dry	1,212
<u>Georgia</u>			
Blue Circle, Inc.	Atlanta, GA	2-dry	614
Medusa Cement Co.	Clinchfield, GA	1-wet, 1-dry	795

TABLE 7-9. PORTLAND CEMENT PRODUCTION FACILITIES (1995)(CONTINUED)

Company	Location	No./type of kiln	Clinker Capacity (tons/yr)
<u>Iowa</u>			
Holnam, Inc.	Mason City, IA	2-dry	919
Lafarge Corp.	Bufalo, IA	1-dry	927
Lehigh Portland Cement	Mason City, IA	1-dry	804
<u>Idaho</u>			
Ash Grove Cement Co.	Inkom, ID	2-wet	259
<u>Illinois</u>			
Centex	La Salle, IL	1-dry	576
Dixon-Marquette	Dixon, IL	4-dry	521
Lafarge Corp.	Grand Chain, IL	2-dry	1,159
Lone Star Industries	Oglesby, IL	1-dry	574
<u>Indiana</u>			
Essroc Materials	Logansport, IN	2-wet	453
Essroc Materials	Speed, IN	2-dry	1,013
Lehigh Portland Cement	Mitchell, IN	3-dry	729
Lone Star Industries	Greencastle, IN	1-wet	723
<u>Kansas</u>			
Ash Grove Cement Co.	Chanute, KS	2-wet	484
Lafarge Corp.	Fredonia, KS	2-wet	384
Monarch Cement Co.	Humboldt, KS	3-dry	672
RC Cement Co., Inc.	Independence, KS	4-dry	299
<u>Kentucky</u>			
Kosmos Cement Co.	Kosmosdale, KY	1-dry	778
<u>Maryland</u>			
Essroc Materials	Frederick, MD	2-wet	372
Independent Cement Corp.	Hagerston, MD	1-dry	519
Lehigh Portland Cement	Union Bridge, MD	4-dry	990
<u>Maine</u>			
Dragon Products Co.	Thomaston, ME	1-wet	431
<u>Michigan</u>			
Holnam, Inc.	Dundee, MI	2-wet	1,054
Lafarge Corp.	Alpena, MI	5-dry	2,267
Medusa Cement Co.	Charlevoix, MI	1-dry	1,273
St. Marys Cement Corp.	Detroit, MI	1-wet	649

TABLE 7-9. PORTLAND CEMENT PRODUCTION FACILITIES (1995)(CONTINUED)

Company	Location	No./type of kiln	Clinker Capacity (tons/yr)
<u>Missouri</u>			
Continental Cement Co., Inc.	Hannibal, MO	1-wet	597
Holnam, Inc.	Clarksville, MO	1-wet	1,297
Lafarge Corp.	Sugar Creek, MO	2-dry	505
Lone Star Industries	Cape Girardeau, MO	1-dry	1,188
RC Cement Co., Inc.	Festus, MO	2-dry	1,269
<u>Mississippi</u>			
Holnam, Inc.	Artesia, MS	1-wet	476
<u>Montana</u>			
Ash Grove Cement Co.	Montana City, MT	1-wet	301
Holnam, Inc.	Three Forks, MT	1-wet	350
<u>Nevada</u>			
Ash Grove Cement Co.	Louisville, NE	2-dry	927
<u>New Mexico</u>			
Rio Grande Cement Corp.	Tijeras, NM	2-dry	475
<u>New York</u>			
Blue Circle, Inc.	Ravena, NY	2-wet	1,692
Glens Falls Cement Co., Inc.	Glens Falls, NY	1-dry	509
Independent Cement Corp.	Catskill, NY	1-wet	658
<u>Ohio</u>			
Lafarge Corp.	Paulding, OH	2-wet	501
Southdown, Inc.	Fairborn, OH	1-dry	598
<u>Oklahoma</u>			
Blue Circle, Inc.	Tulsa, OK	2-dry	649
Holnam, Inc.	Ada, OK	2-wet	598
Lone Star Industries	Pryor, OK	3-dry	684
<u>Oregon</u>			
Ash Grove Cement Co.	Durkee, OR	1-dry	524
<u>Pennsylvania</u>			
Allentown Cement Co., Inc.	Blandon, PA	2-dry	948
Armstrong Cement & Sup. Corp.	Cabot, PA	2-wet	323
Essroc Materials	Nazareth, PA	1-dry	1,174
Essroc Materials	Nazareth, PA	4-dry	583
Essroc Materials	Bessemer, PA	2-wet	575

TABLE 7-9. PORTLAND CEMENT PRODUCTION FACILITIES (1995)(CONTINUED)

Company	Location	No./type of kiln	Clinker Capacity (tons/yr)
<u>Pennsylvania (continued)</u>			
Giant Cemenet Holding, Inc.	Bath, PA	2-wet	601
Kosmos Cement Co.	Pittsburgh, PA	1-wet	384
Lafarge Corp.	Whitehall, PA	3-dry	870
Lehigh Portland Cement	York, PA	1-wet	99
Medusa Cement Co.	Wampum, PA	3-dry	673
RC Cement Co., Inc.	Stockertown, PA	2-dry	911
<u>South Carolina</u>			
Blue Circle, Inc.	Harleyville, SC	1-dry	745
Giant Cement Holding, Inc.	Harleyville, SC	4-wet	867
Holnam, Inc.	Holly Hill, SC	2-wet	1,064
<u>South Dakota</u>			
Dacotah Cement	Rapid City, SD	2-wet, 1-dry	893
<u>Tennessee</u>			
RC Cement Co., Inc.	Chattanooga, TN	2-wet	438
Southdown, Inc.	Knoxville, TN	1-dry	638
<u>Texas</u>			
Alamo Cement Co.	San Antonio, TX	1-dry	846
Capitol Aggregates, Inc.	San Antonio, TX	1-wet, 1-dry	839
Holnam, Inc.	Midlothian, TX	1-dry	1,117
Lehigh Portland Cement	Waco, TX	1-wet	85
Lone Star Industries	Sweetwater, TX	3-dry	485
North Texas Cement	Midlothian, TX	3-wet	851
Southdown, Inc.	Odessa, TX	2-dry	526
Sunbelt Cmenet Corp.	New Braunfels, TX	1-dry	980
Texas Industries	Midlothian, TX	4-wet	1,258
Texas Industries	New Braunfels, TX	1-dry	847
Texas-Lehigh Cement Co.	Buda, TX	1-dry	1,103
<u>Utah</u>			
Ash Grove Cement Co.	Nephi, UT	1-dry	789
Holnam, Inc.	Morgan, UT	2-wet	317
<u>Virginia</u>			
Roanoke Cement Co.	Cloverdale, VA	1-dry	946

TABLE 7-9. PORTLAND CEMENT PRODUCTION FACILITIES (1995)(CONTINUED)

Company	Location	No./type of kiln	Clinker Capacity (tons/yr)
<u>Washington</u>			
Ash Grove Cement Co.	Seattle, WA	1-dry	747
Holnam, Inc.	Seattle, WA	1-wet	446
<u>West Virginia</u>			
Capitol Cement Corporation	Martinsburg, WV	3-wet	955
Centex	Fernley, WV	2-dry	480
Royal Cement Co., Inc.	Logandale, WV	1-dry	195
<u>Wyoming</u>			
Centex	Laramie, WY	2-dry	644

Source: Reference 20.

7.6 Open Burning Of Scrap Tires

7.6.1 Process Description

Approximately 240 million vehicle tires are discarded annually.²¹ Although viable methods for recycling exist, less than 25 percent of discarded tires are recycled; the remaining 175 million are discarded in landfills, stockpiles, or illegal dumps.²² Although it is illegal in many States to dispose of tires by open burning, fires often occur at tire stockpiles and through illegal burning activities. These fires generate a huge amount of heat and are difficult to extinguish (some tire fires continue for months). Arsenic is a component of tires and is emitted from the combustion of these tires.

7.6.2 Emission Factors

Table 7-10 contains emission factors for the open burning of tires.²² The average emission factor presented represents the average of tests performed on the simulated open burning of chunk (defined as one-quarter or one-sixth of an entire tire) and shredded tires. When estimating emissions from an accidental tire fire, note that emissions from burning tires are generally dependent on the burn rate of the tire. A greater potential for emissions exists at lower burn rates, such as when a tire is smoldering rather than burning out of control.²²

Besides accidental or illegal open burning of tires, waste tires are incinerated for energy recovery and disposal purposes. Tires are combusted at tire-to-energy facilities, cement kilns, tire manufacturing facilities, and as supplemental fuel in boilers. No emission factors for arsenic from tire incineration have been located.

7.6.3 Source Location

Open burning of scrap tires can occur at permitted landfills that stockpile scrap tires, at closed landfills that already contain scrap tires, and at illegal dumpsites where tires are discarded.

TABLE 7-10. ARSENIC EMISSION FACTORS FOR OPEN BURNING OF SCRAP TIRES

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/1000 ton ^a	Emission Factor Rating
5-03-002-03	Simulated Open Burning of Chunk Automobile Tires	None	1.00×10^{-1}	C
	Simulated Open Burning of Shredded Automobile Tires	None	4.00×10^{-1}	C

Source: Reference 23.

^a Emission factors are expressed in lb of pollutant emitted per 1000 ton of waste incinerated. To convert to kg per 1000 metric tons (kg/1000 tonnes), multiply by 0.907.

The fires can start by accident or are intentionally set by arsonists, and thus are unpredictable as to where and when they will occur.

7.7 Grain Milling

Milling is the process of converting grain into flour by mechanical means. The grain is cleaned and a small amount of water is added to prevent the outer part of the kernel from pulverizing. The moistened grain is mechanically crushed slightly and sheared into chunks. The product is sifted to remove the germ and the bran, and the chunks are size separated. The larger chunks are recrushed and the intermediate-sized chunks are ground between smooth rolls.²³ Finally, screens are used to remove undersized and oversized materials, and the final product is transferred to the bagging area, to storage, or to bulk load-out.

The modern milling industry applies many innovations in their process operations. One example is the production of free-flowing flour made by agglomerating the flour particles into clusters by the addition of moisture and spray-drying. This allows for the separation of high protein and high-starch fractions and permits a wide range of custom blending.²⁴

Limited arsenic emissions data are available for this category. One report from tests conducted at a rice milling plant was available for review and emission factors developed from that report are presented in Table 7-11. Another test conducted at a feed mill under the California AB 2588 (“Hot Spots”) program reported that arsenic was not detected from the baghouse discharge or milling operations.²⁴

7.8 Process Heaters

A process heater is similar to an industrial boiler in that heat liberated by the combustion of fuels is transferred by radiation and convection to fluids contained in tubular coils. Process heaters are used in many chemical manufacturing operations to provide steam and heat input essential to chemical processing. They are also used as feed preheaters and as reboilers for some distillation operations. The fuels used in process heaters include natural gas, refinery offgases, and various grades of fuel oil. Gaseous fuels account for about 90 percent of the energy consumed by process heaters.

There are many variations in the design of process heaters depending on their application. In general, the radiant section consists of the burner(s), the firebox, and tubular coils containing the process fluid. Most heaters also contain a convective section in which heat is recovered from hot combustion gases by convective heat transfer to the process fluid.

Process heaters (and boilers) are most applicable where the potential exists for heat recovery from the combustion of the vent stream. For example, vent streams with a high VOC concentration and high flow rate can provide enough equivalent heat value to act as a substitute for fuel that would otherwise be needed.

Emissions data for this category are limited. Emission factors developed from three available test reports are presented in Table 7-12.^{25,26,27}

TABLE 7-11. ARSENIC EMISSION FACTORS FOR GRAIN MILLING

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/ton ^a	Emission Factor Range in lb/ton ^a	Emission Factor Rating
3-02-007-73	Grain Milling, Rice Drying	None	1.30×10^{-6}	1.10×10^{-6} - 1.40×10^{-6}	U
3-02-007-74	Grain Milling, Rice Cleaning/Millhouse	None	1.20×10^{-6}	9.95×10^{-7} - 1.26×10^{-6}	U

Source: Reference 25.

^a Emission factors are expressed in lb of pollutant emitted per ton of grain processed. To convert to kg per metric ton (kg/tonne), multiply by 0.5.

TABLE 7-12. ARSENIC EMISSION FACTORS FOR PROCESS HEATERS

SCC Number	Emission Source	Control Device	Average Emission Factor in lb/MMBtu ^a	Emission Factor Range in lb/MMBtu ^a	Emission Factor Rating	Reference
3-10-004-13	Oil and Gas Production, Process Heaters, Crude Oil, Steam Generator	None	9.49×10^{-6}	4.14×10^{-6} - 1.27×10^{-5}	U	26
3-06-001-01	Petroleum Industry, Pipelines, Oil-Fired Process Heaters	None	4.00×10^{-6}	3.80×10^{-6} - 4.30×10^{-6}	U	27
3-10-004-02	Oil and Gas Production, Residual Oil-Fired Process Heater	None	2.50×10^{-6}	9.70×10^{-7} - 5.16×10^{-6}	U	28

^a Emission factors are expressed in lb of pollutant emitted per million Btu of heat input. To convert to grams per MegaJoule (g/MJ), multiply by 0.43.

7.9 Cotton Production and Ginning

Until 1993, arsenic acid (H_3AsO_4) was used as a cotton desiccant in some areas of the U.S. Its use has contributed to arsenic emissions to the atmosphere both from the field where the cotton was grown and from cotton gins.

Prior to mechanical stripping (harvesting) of cotton, the green leaves must be dried to prevent fiber staining and to prevent unacceptable moisture levels in the fiber. Such conditions lower the quality of the cotton. In many cotton producing areas a killer frost occurs before harvest, thus desiccating the leaves. However, in areas without such a frost, a chemical desiccant is needed. Texas and Oklahoma are the primary areas where chemical desiccation has been practiced.

The use of arsenic acid as a cotton desiccant began in 1956 and continued through 1993 when it was banned from use by the EPA.²⁸ In practice, about 3 pints of arsenic acid per acre was applied by ground or aerial spraying. It has been estimated that only about 5 percent of the arsenic acid reached the intended crop. The remaining overspray either drifted from the field or was deposited in field soil.

Sources of potential arsenic emissions to the atmosphere have included application overspray; arsenic-containing dust and plant matter emitted during harvesting; arsenic-containing dust, plant matter, and lint emitted during ginning; and wind blown soil from fields where spraying has been conducted.²⁹

Since the use of arsenic acid as a cotton desiccant has been banned, the emissions potential has been largely eliminated. In some areas where spraying has occurred over many years, it is possible that arsenic accumulated in the soils could still be emitted as windblown dust. However, that potential will continue to diminish over time.

Limited arsenic emissions data for cotton ginning were available in the literature; however, these data are eighteen to twenty years old, and were generated from tests at a cotton

gin which received cotton treated with arsenic acid. The ginning process has changed since that time, and the data are deemed no longer applicable and are therefore not included in this document.

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SECTION 8.0

SOURCE TEST PROCEDURES

Arsenic emissions can be measured by a number of methods. The following methods are applicable for measuring emissions of arsenic in ambient air and arsenic contained in stack gas emissions: (1) National Institute of Occupational Safety and Health (NIOSH) Method 7300,¹ (2) NIOSH Method 7900,² (3) NIOSH Method 7901,¹ (4) NIOSH Method 5022,³ (5) EPA's Methodology for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method), Appendix B, and Appendix G modified Methodology for the Determination of Lead in Suspended Particulate Matter Collected From Ambient Air (40 CFR 50),⁴ (6) EPA Method 29,⁵ (7) EPA Method 108,⁶ (8) EPA BIF Method, Section 3.0,⁷ (9) California Air Resources Board (CARB) Method 423,⁸ and (10) CARB Draft Method 436m.⁹

All of the NIOSH methods and EPA 40 CFR 50 Appendixes apply to the collection and analysis of arsenic from ambient air. EPA Method 29 and BIF, Section 3.0, are part of the Boiler and Industrial Furnace (BIF) Regulations and are used to sample for total inorganic and organic arsenic, and other metals, in stack gases. EPA Method 108 and CARB Method 423 are used to sample specifically for inorganic and organic arsenic in stack gases. CARB Draft Method 436 is used to sample for total inorganic and organic arsenic, and other metals, in stack gases.

Sections 8.1 and 8.2 of this report summarize the field sampling procedures for measuring arsenic in ambient air and stack gases, respectively. Section 8.3 describes the different analytical techniques used to analyze and measure the amount of arsenic collected in ambient air and stack gas samples.

8.1 Ambient Air Sampling Methods

Ambient air concentrations of arsenic can be measured using Methodology for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method) and modified Methodology for the Determination of Lead in Suspended Particulate Matter Collected From Ambient Air; and NIOSH Methods 7300, 7900, 7901 and 5022. The following methods are described in detail below.

8.1.1 Methodology for the Determination of Suspended Particulate Matter in the Atmosphere (High-Volume Method) and Modified Methodology for the Determination of Lead in Suspended Particulate Matter Collected from Ambient Air

A high volume sampler is used to collect total suspended particulate (TSP) matter. Figure 8-1 shows a simplified diagram of the components of the high-volume ambient air sampling equipment.¹⁰ The equipment is mounted in an enclosed shelter equipped with a roof. Ambient air is drawn under the roof of the shelter through a pre-weighed glass-fiber filter. The high-volume sampler should be operated for 24 hours at an average flow rate of 1.7 cubic meters per minute (m^3/min). The approximate concentration range of the method is 2 to $750 \mu\text{g}/\text{m}^3$. However, the lower limit is determined by the sensitivity of the balance used in the analysis by the laboratory, and the upper limit is affected by various factors, such as variability of filters used in the sampler, and particle size distribution of the sample.

After sampling, the filter is removed and sent to a laboratory for analysis. The method is then modified to prepare and analyze the high-volume filter sample for arsenic instead of lead. The filter is weighed several times until a constant weight is obtained and then the filter is digested in an acid solution and analyzed for total arsenic content either by atomic absorption spectrophotometry (AAS) or inductively coupled plasma (ICP) emission spectroscopy.

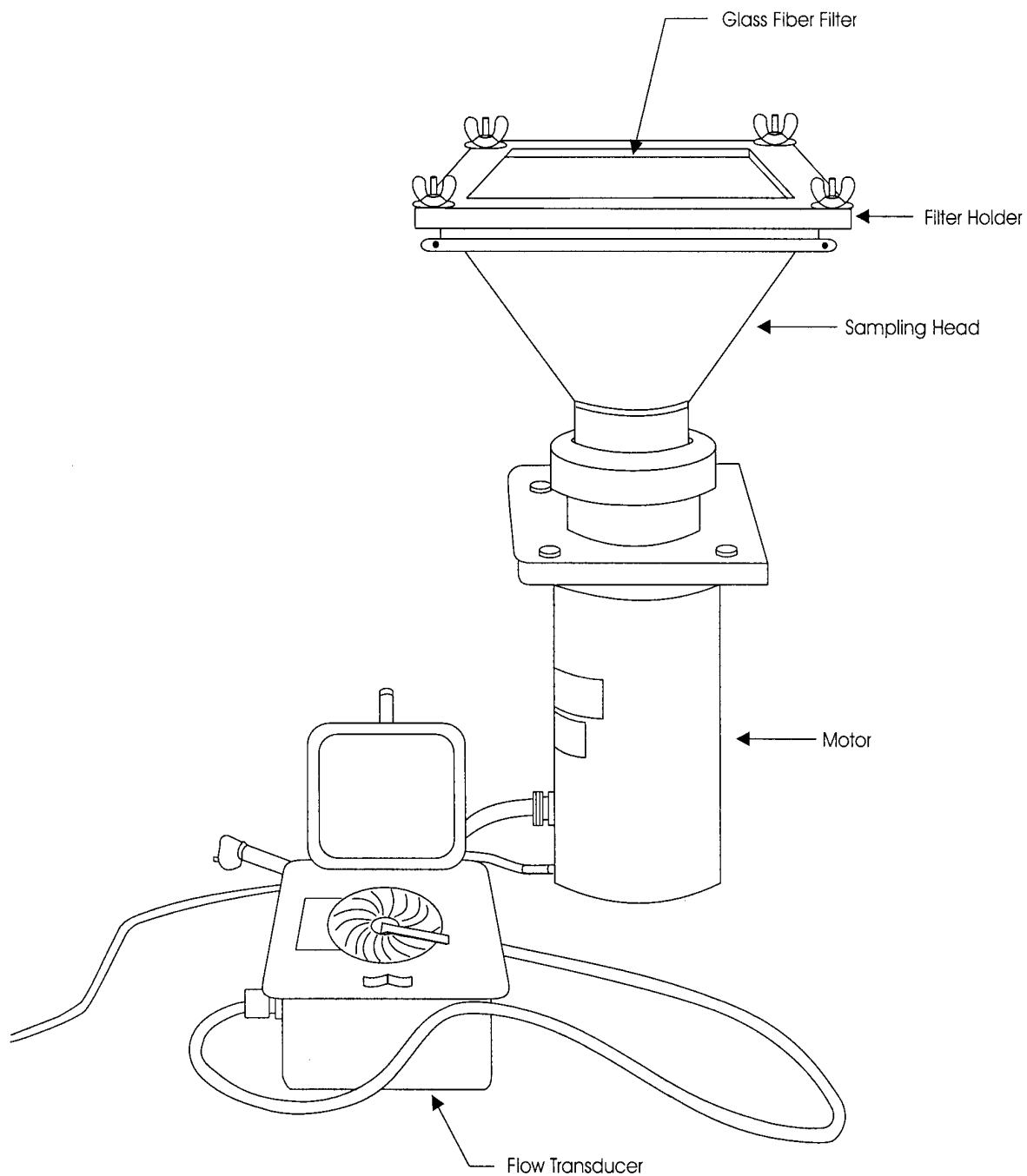


Figure 8-1. Components of a High-Volume Ambient Air Sampler for Arsenic

Source: Reference 10.

One advantage of the High-Volume Method (Appendix B) and the Appendix G Modified Lead Method is that the ambient air sample is collected over a 24-hour period, which can encompass all types of weather conditions, particularly temperature changes, and the range of emission source activities that occur throughout a 24-hour period.

One disadvantage of the high-volume sampling method is that it was designed for sampling only total inorganic arsenic compounds in suspended particulate matter (PM). Inorganic arsenic cannot be speciated and most organic arsenic compounds cannot be detected. A second disadvantage is that the high-volume method is very dependent on meteorological conditions. Any change in wind speed or direction and any amount of precipitation can influence the sample results. To interpret the effects of weather conditions on the sample results, meteorological data must be recorded during the sampling period.

8.1.2 NIOSH Method 7300 - Methodology for the Determination of Elements by Inductively Coupled Plasma (ICP)

Method 7300 can be used to sample for elemental arsenic and various metals in ambient air. This method collects particulate metals only. Samples are collected on a mixed cellulose ester membrane filter (MCEF), 0.8 μm pore size, 37 mm diameter, with a backup pad, placed into a cassette filter holder. A calibrated personal sampling pump is used to pull air through the cassette holder at a flow rate between 1 and 4 L/min for a total sample size of 200 to 2,000 L.

The filters and backup pads, housed inside the cassette, are sent to the laboratory for analysis. At the laboratory, the filters are ashed using a nitric acid/perchloric acid solution and diluted to a known final volume. After the initial sample preparation step, samples are analyzed by ICP or AAS at the specific wavelength for arsenic analysis.

Samples collected using NIOSH 7300 are relatively stable, but it is important not to exceed a filter loading of approximately 2 mg of total dust.

8.1.3 NIOSH Method 7900 - Methodology for the Determination of Arsenic and Compounds, as Arsenic, using Direct-Aspiration (Flame) Atomic Absorption Spectroscopy (AAS)

Method 7900 can be used to sample for arsenic in ambient air. This method collects only particulate arsenic and is an elemental analysis, not compound specific. Samples are collected on a MCEF, 0.8 μm pore size, 37 mm diameter, with a backup pad, placed into a cassette filter holder. A calibrated personal sampling pump is used to pull air through the cassette holder at a flow rate of between 1 and 3 L/min for a total sample size of 30 to 1,000 L.

The filters and backup pads, housed inside the cassette, are sent to the laboratory for analysis. At the laboratory, the filters are ashed using a nitric acid/perchloric acid solution and diluted to a known final volume. After the initial sample preparation step, samples are analyzed for arsenic by direct-aspiration (flame) AAS.

Samples collected using NIOSH 7900 are relatively stable if refrigerated, but it is important not to exceed a filter loading of approximately 2 mg total dust. Again, this method collects particulate arsenic only and not volatile organic arsenic compounds, such as arsenic trioxide.

8.1.4 NIOSH Method 7901 - Methodology for the Determination of Arsenic Trioxide, as Arsenic, by Graphite Furnace Atomic Absorption (GFAA)

Method 7901 can be used to sample for particulate arsenic compounds as well as arsenic trioxide vapor. Samples are collected on treated MCEFs, 0.8 μm pore size, 37 mm diameter, and a cellulose backup pad, placed into a cassette filter holder. The filter and backup pad is previously treated with a sodium carbonate/glycerol solution. A calibrated personal sampling pump is used to pull air through the cassette holder at a flow rate of between 1 and 3 L/min for a total sample size of 30 to 1,000 L.

The filters and backup pads, housed inside the cassette, are sent to the laboratory for analysis. At the laboratory, the filters and backup pads are digested on a hot plate using

concentrated nitric acid and 30 percent hydrogen peroxide. The samples are then diluted to a known final volume. After the initial sample preparation step, samples are analyzed for arsenic by GFAA.

Samples collected using NIOSH 7901 are relatively stable, but it is important not to exceed a filter loading of approximately 2 mg total dust.

8.1.5 NIOSH Method 5022 - Methodology for the Determination of Organo-Arsenic Compounds by Ion Chromatography (IC)/Graphite Furnace Atomic Absorption (GFAA)

Method 5022 can be used to sample for particulate organo-arsenic compounds. Samples are collected on a polytetrafluoroethylene (PTFE) backed membrane filter, 1 µm pore size, 37 mm diameter, with a backup pad, placed into a cassette filter holder. A calibrated personal sampling pump is used to pull air through the cassette holder at a flow rate between 1 and 3 L/min for a total sample volume of 50 to 1,000 L.

The filters and backup pads, housed inside the cassette, are sent to the laboratory for analysis. At the laboratory, the filter is sonicated and extracted in a sodium carbonate/sodium bicarbonate/sodium borohydride solution. The samples are then analyzed for organo-arsenic compounds by IC/GFAA.

8.2 Stationary Source Sampling Methods

Various methods are available for sampling stack gas concentrations of arsenic: EPA Method 29, EPA Method 108, EPA BIF Method, and CARB Methods 423 and Draft 436. These methods are described in this section.

8.2.1 EPA Method 29 - Determination of Metals Emissions from Stationary Sources

EPA Method 29 can be used to sample PM and total inorganic and organic arsenic compounds isokinetically from stack gases. The sampling train for Method 29 is a modification of the EPA Method 5¹¹ sampling train, and is shown in Figure 8-2.¹²

Particulate arsenic with a particle size diameter greater than or equal to 0.3 μm is collected through a glass nozzle and probe onto a pre-weighed glass fiber filter. Particulate arsenic with a particle size diameter less than 0.3 μm and arsenic compounds in the vapor phase pass through the filter and are collected in a dilute nitric acid/hydrogen peroxide solution contained in the train impingers. The nozzle/probe and both halves of the filter holder are washed with dilute nitric acid. The nozzle/probe wash, two separate filter holder washes, filter, and impinger solution are sent to a laboratory, where they are digested in an acid solution and analyzed for arsenic content either by AAS or ICP. The samples collected on the filter and in the impinger solution can be analyzed separately to differentiate between the amount of particulate arsenic and arsenic in the gaseous phase.

The exact run time and volume sampled varies from source to source depending on the required detection limit. Typically, the Method 29 train is run for 2 hours and collects approximately 2.55 m^3 of stack gas. According to the method, the ICP analytical detection limit is 53 ng/ml of total arsenic, and the GFAA analytical detection limit is 1 ng/ml. The upper range can be extended considerably by diluting the sample prior to analysis. However, actual sample analytical detection limits are sample dependent and may vary due to the sample matrix. Also, laboratory instrumentation may affect the detection limit.

Although it is the preferred method for sampling stack gas streams and can measure several metals at one time, the method cannot be used to speciate inorganic or organic arsenic compounds.

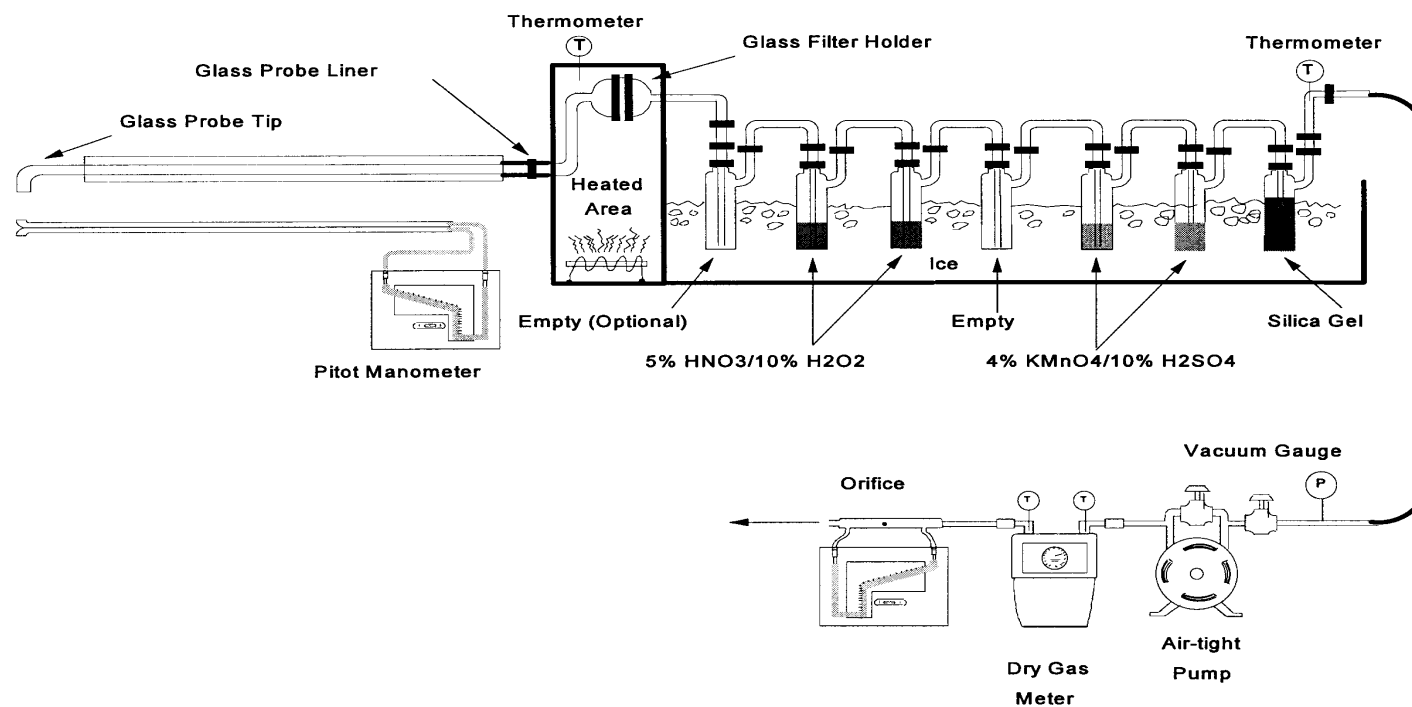


Figure 8-2. EPA Method 29, BIF Method, and CARB Draft Method 436 Sampling Train

Source: Reference 12.

8.2.2 EPA Method 108 - Methodology for the Determination of Particulate and Gaseous Arsenic Emissions

EPA Method 108 can be used to sample PM and total inorganic and organic arsenic compounds isokinetically from stack gases. The Method 108 sampling train is a modified EPA Method 5 sampling train and is shown in Figure 8-3.⁸

Particulate arsenic with a particle size diameter greater than or equal to 0.3 μm is collected through a glass nozzle and probe onto a pre-weighed glass fiber filter. Particulate arsenic with a particle size diameter less than 0.3 μm and arsenic compounds in the vapor phase pass through the filter and are collected in deionized water contained in the train impingers. The nozzle/probe, front half of the filter housing, and glassware containing the impinger solution are washed with a sodium hydroxide solution. The washes, filter, and impinger solution are sent to a laboratory, where they are digested in an acid solution and analyzed for arsenic content either by AAS or ICP. The samples collected on the filter and in the impinger solution can be analyzed separately to differentiate between the amount of particulate arsenic and gaseous arsenic.

The exact run time and volume sampled varies from source to source depending on the required detection limit. Actual sample analytical detection limits are sample dependent and may vary due to the sample matrix. Also, laboratory instrumentation may affect the detection limit.

8.2.3 EPA BIF Method Section 3.0 - Methodology for the Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Combustion Processes

The EPA BIF method can be used to sample PM and total inorganic and organic arsenic compounds isokinetically from stack gases. The BIF method sampling train is a modified EPA Method 5 sampling train, and is identical to the Method 29 sampling train, and is shown in Figure 8-2.

The EPA BIF Method sampling, analytical procedures, and analytical detection limits are identical to Method 29; refer to Section 8.2.1 for the discussion.

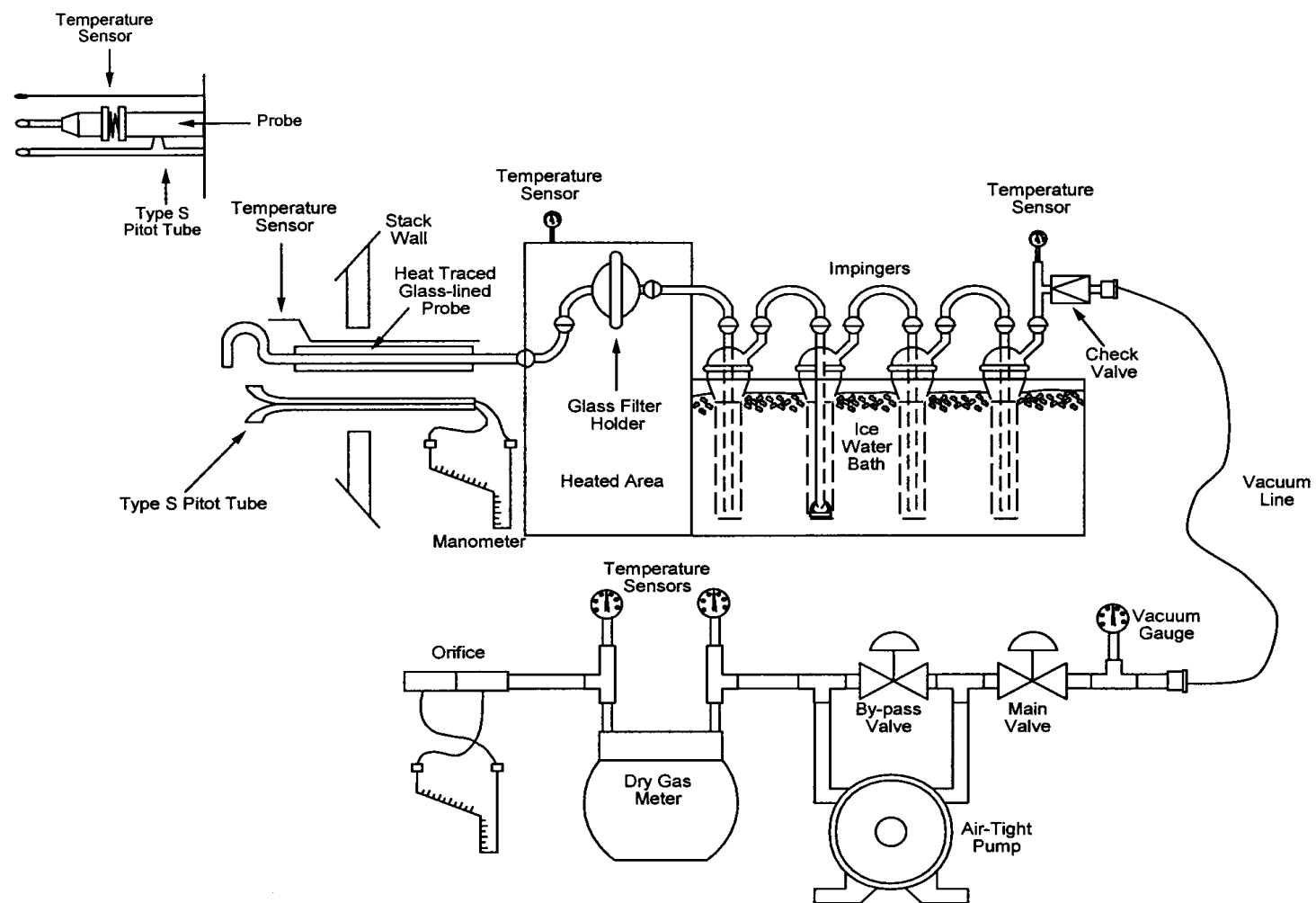


Figure 8-3. EPA Method 108 and CARB Method 423 Sampling Train

Source: Reference 8.

8.2.4 CARB Method 423 - Methodology for the Determination of Particulate and Gaseous Inorganic Arsenic Emissions from Stationary Sources

CARB Method 423 can be used to sample PM and total inorganic and organic arsenic compounds isokinetically from stack gases. The Method 423 sampling train is similar to EPA Method 5 sampling train, and is identical to the Method 108 sampling train, see Figure 8-3.

CARB Method 243 sampling and analytical procedures are identical to Method 108; refer to Section 8.2.2 for the discussion.

8.2.5 CARB Draft Method 436 - Determination of Multiple Metals Emissions from Stationary Sources

Draft Method 436 can be used to sample PM and total inorganic and organic arsenic compounds isokinetically from stack gases. The sampling train for Draft Method 436 is a modification of the EPA Method 5 sampling train, and is identical to EPA Method 29 (see Figure 8-2).

Draft Method 436 sampling, analytical procedures, and analytical detection limits are identical to EPA Method 29; refer to Section 8.2.1 for the discussion.

8.3 Analytical Techniques For The Measurement Of Arsenic

The most common technique for measuring total arsenic in samples is spectroscopy. The two spectroscopic techniques used most by environmental laboratories are AAS and ICP. AAS is the most common method used to measure total arsenic. The advantages to AAS are that the method is simple, rapid, and applicable to a large number of metals. Samples other than drinking water must be acid-digested prior to analysis. Three types of AAS methods for measuring total arsenic are direct aspiration (flame), graphite furnace, and hydride-generation.

The second most common technique for measuring total arsenic in samples is ICP, which allows simultaneous, or sequential, determination of several metals in a sample during a single analytical measurement. Samples must be acid-digested prior to analysis.

Although not as common, another technique for measuring arsenic in samples is ion chromatography (IC) connected to GFAA.

8.3.1 Direct Aspiration (Flame) Atomic Absorption Spectroscopy (AAS)

Method 7000¹³ specifies the procedure for analyzing samples using direct-aspiration (flame) AAS. In direct-aspiration (flame) AAS, a sample is aspirated and atomized in an air/acetylene flame. A light beam from a hollow cathode lamp, whose cathode is made of the element being measured, is directed through the flame into a monochromator, and onto a detector that measures the amount of light absorbed. Absorption depends upon the presence of free, unexcited ground-state atoms in the flame. Because the wavelength of the light beam is characteristic of only the element being measured, the light energy absorbed by the flame is a measure of the concentration of that element in the sample. With flame AAS, if the proper flame and analytical conditions are not used, chemical and ionization interferences can occur. Flame AAS is normally performed as a single element analysis. If direct-aspiration (flame) AAS techniques do not provide adequate sensitivity, graphite furnace techniques can be used.

8.3.2 Graphite Furnace Atomic Absorption (GFAA) Spectroscopy

Method 7060¹³ specifies the procedure for analyzing samples for total arsenic using graphite furnace AAS. The principle of graphite furnace AAS is essentially the same as for direct-aspiration (flame) AAS, except a furnace rather than a flame is used to atomize the sample. In graphite furnace AAS, a representative aliquot of a sample is placed in a graphite tube in the furnace, evaporated to dryness, charred, and atomized. The radiation from a given excited element is passed through the vapor containing ground-state atoms of that element. The intensity of the transmitted radiation decreases in proportion to the amount of the ground-state element in the vapor. The metal's atoms to be measured are placed in the beam of radiation by increasing

the temperature of the furnace, thereby causing the injected sample to be volatilized. A monochromator isolates the characteristic radiation from the hollow cathode lamp or electrodeless discharge lamp, and a photosensitive device measures the attenuated transmitted radiation.

The major advantage of GFAA is that it affords extremely low detection limits. It is the easiest technique to perform on relatively clean samples. Because this technique is so sensitive, however, interferences can be a problem; finding the optimum combination of digestion, heating times, and temperatures, and matrix modifiers can be difficult for complex matrices.

8.3.3 Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy

Method 6010¹³ specifies the procedures for analyzing samples using ICP. The ICP method measures element-emitted light by optical spectrometry. The sample is nebulized and the resulting aerosol is transported to the plasma torch, where excitation occurs. Characteristic atomic-line emission spectra are produced by radio-frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and the intensities of the lines are monitored by photomultiplier tubes. The photocurrents from the photomultiplier tubes are processed and controlled by a computer.

The primary advantage of ICP is that it allows simultaneous or rapid sequential determination of many elements in a short time. The primary disadvantage is background radiation from other elements and the plasma gases. Although all ICP instruments utilize high-resolution optics and background correction to minimize these interferences, analysis for traces of metals in the presence of a large excess of a single metal is difficult.

8.3.4 Hydride Generation Atomic Absorption (HGAA) Spectroscopy

Method 7061¹³ specifies the procedure for analyzing samples for total arsenic using HGAA. HGAA utilizes a chemical reduction to reduce and separate arsenic selectively from a digested sample along with standard AAS techniques.

The primary advantage of this technique is that arsenic can be isolated and quantitated from complex samples.

A disadvantage of HGAA is that significant interferences will occur when easily reduced metals are present, and/or when high concentrations of transition metals are present. Also, oxidizing agents, such as oxides of nitrogen, may remain after the sample has been digested.

8.3.5 Ion Chromatography (IC)/GFAA

NIOSH Method 5022 specifies the procedure for analyzing air samples for total arsenic using an IC connected to GFAA. Ion chromatography is a separation technique used for the analysis of ionic species. Separation of components in a sample can be achieved with the use of a mobile phase (eluent), and a stationary phase (a specific type of polymeric resin bed inside of a column). A sample analyte is introduced into the flowstream of the mobile phase (eluent) and is carried onto the stationary phase (column). The analyte then undergoes a separation process based on its affinity for either of the mobile or stationary phases.

With NIOSH Method 5022, the IC detector is bypassed, and the sample flows into an arsine generator where gaseous arsines are formed. A gas-liquid separator is then used to flow the sample into the GFAA where the sample is quantitated.

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APPENDIX A

EMISSION FACTOR SUMMARY TABLE

TABLE A-1. SUMMARY OF EMISSION FACTORS BY SOURCE CLASSIFICATION CODES

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
1-01-009-01	Wood Waste-Fired Boiler (Bark Fired)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-01-009-02	Wood Waste-Fired Boiler (Wood/Bark Fired)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-01-009-03	Wood Waste-Fired Boiler (Wood Fired)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-01-009-03	Wood Waste-Fired Boiler (Wood Fired)	Limestone Injection/Thermal de-NO _x with Ammonia Injection/Water Treatment/Multicyclone/FF	7.87×10^{-7}	lb/MMBtu	8.55×10^{-8} - 1.37×10^{-6}	U
1-02-009-01	Wood Waste-Fired Boiler (Bark Fired, > 50,000 lb steam)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-02-009-02	Wood Waste-Fired Boiler (Wood/Bark Fired, > 50,000 lb steam)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-02-009-03	Wood Waste-Fired Boiler (Wood Fired, > 50,000 lb steam)	Wet Scrubber - Medium Efficiency	2.50×10^{-5}	lb/MMBtu	7.20×10^{-6} - 3.70×10^{-5}	U
1-02-009-03	Wood Waste-Fired Boiler (Wood Fired, > 50,000 lb steam)	Multiple Cyclone without Fly Ash Reinjection/Wet Scrubber - Medium Efficiency	7.20×10^{-6}	lb/MMBtu	6.00×10^{-6} - 9.10×10^{-6}	U
1-02-009-03	Wood Waste-Fired Boiler (Wood Fired, > 50,000 lb steam)	Multiple Cyclone without Fly Ash Reinjection	7.60×10^{-6}	lb/MMBtu	8.40×10^{-7} - 2.10×10^{-5}	U
1-02-009-03	Wood Waste-Fired Boiler (Wood Fired, > 50,000 lb steam)	Multiple Cyclone without Fly Ash Reinjection/ESP - Medium Efficiency	$< 4.20 \times 10^{-7}$	lb/MMBtu	$< 3.20 \times 10^{-7}$ - 6.10×10^{-7}	U
1-02-009-03	Wood Waste-Fired Boiler (Wood Fired, > 50,000 lb steam)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-02-009-04	Wood Waste-Fired Boiler (Bark Fired, < 50,000 lb steam)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
1-02-009-05	Wood Waste-Fired Boiler (Wood/Bark Fired, < 50,000 lb steam)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-02-009-06	Wood Waste-Fired Boiler (Wood Fired, < 50,000 lb steam)	Multiple Cyclone without Fly Ash Reinjection	1.10×10^{-5}	lb/MMBtu	5.00×10^{-6} - 1.60×10^{-5}	U
1-02-009-06	Wood Waste-Fired Boiler (Wood Fired, < 50,000 lb steam)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-02-009-06	Wood Waste-Fired Boiler (Wood Fired, < 50,000 lb steam)	Scrubber	$< 5.34 \times 10^{-6}$	lb/MMBtu	$< 2.05 \times 10^{-6}$ - $< 1.06 \times 10^{-5}$	U
1-02-009-07	Wood Waste-Fired Boiler (Wood Cogeneration)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-03-009-01	Wood/Bark-Fired Boiler (Bark-Fired)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-03-009-02	Wood/Bark-Fired Boiler (Wood/Bark-Fired)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-03-009-03	Wood/Bark-Fired Boiler (Wood-Fired)	None	8.80×10^{-5}	lb/ton	1.40×10^{-6} - 2.40×10^{-4}	C
1-01-001-02	Anthracite Coal Traveling Grate (Overfeed) Stoker	None	1.90×10^{-4}	lb/ton	ND - 2.40×10^{-4}	E
1-01-002-01	Bituminous Coal Pulverized Coal: Wet Bottom	None	5.38×10^{-4}	lb/MMBtu	---	E
1-01-002-02	Bituminous Coal Pulverized Coal: Dry Bottom	None	6.84×10^{-4}	lb/MMBtu	---	E
1-01-002-03	Bituminous Coal Cyclone Furnace	None	1.15×10^{-4}	lb/MMBtu	---	E
1-01-002-04	Bituminous Coal Spreader Stoker	None	---	lb/MMBtu	2.64×10^{-4} - 5.42×10^{-4}	E
1-01-002-05	Bituminous Coal Traveling Grate (Overfeed) Stoker	None	---	lb/MMBtu	5.42×10^{-4} - 1.03×10^{-3}	E

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
1-01-002-21	Subbituminous Coal Pulverized Coal: Wet Bottom	None	5.38×10^{-4}	lb/MMBtu	---	E
1-01-002-22	Subbituminous Coal Pulverized Coal: Dry Bottom	None	6.84×10^{-4}	lb/MMBtu	---	E
1-01-002-23	Subbituminous Coal Cyclone Furnace	None	1.15×10^{-4}	lb/MMBtu	---	E
1-01-002-24	Subbituminous Coal Spreader Stoker	None	---	lb/MMBtu	2.64×10^{-4} - 5.42×10^{-4}	E
1-01-002-25	Subbituminous Coal Traveling Grate (Overfeed) Stoker	None	---	lb/MMBtu	5.42×10^{-4} - 1.03×10^{-3}	E
1-01-003	Lignite Coal Pulverized Coal: Wet Bottom	None	2.73×10^{-3}	lb/MMBtu	---	E
1-01-003	Lignite Coal Pulverized Coal: Dry Bottom	None	1.39×10^{-3}	lb/MMBtu	---	E
1-01-003-03	Lignite Coal Cyclone Furnace	None	---	lb/MMBtu	2.35×10^{-4} - 6.32×10^{-4}	E
1-01-003-04	Lignite Coal Traveling Grate (Overfeed) Stoker	None	---	lb/MMBtu	1.10×10^{-3} - 2.10×10^{-3}	E
1-01-003-06	Lignite Coal Spreader Stoker	None	---	lb/MMBtu	5.38×10^{-4} - 1.10×10^{-3}	E
1-02-001-04	Anthracite Coal Traveling Grate (Overfeed) Stoker	None	1.90×10^{-4}	lb/ton	ND - 2.40×10^{-4}	E
1-02-002-01	Bituminous Coal Pulverized Coal: Wet Bottom	None	5.38×10^{-4}	lb/MMBtu	---	E
1-02-002-02	Bituminous Coal Pulverized Coal: Dry Bottom	None	6.84×10^{-4}	lb/MMBtu	---	E
1-02-002-03	Bituminous Coal Cyclone Furnace	None	1.15×10^{-4}	lb/MMBtu	---	E
1-02-002-04	Bituminous Coal Spreader Stoker	None	---	lb/MMBtu	2.64×10^{-4} - 5.42×10^{-4}	E

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
1-02-002-05	Bituminous Coal Traveling Grate (Overfeed) Stoker	None	---	lb/MMBtu	5.42×10^{-4} - 1.03×10^{-3}	E
1-02-002-06	Bituminous Coal Underfeed Stoker	None	7.90×10^{-3}	lb/MMBtu	---	U
1-02-002-13	Subbituminous Coal Wet Slurry	None	7.44×10^{-5}	lb/MMBtu	---	U
1-02-002-21	Subbituminous Coal Pulverized Coal: Wet Bottom	None	5.38×10^{-4}	lb/MMBtu	---	E
1-02-002-22	Subbituminous Coal Pulverized Coal: Dry Bottom	None	6.84×10^{-4}	lb/MMBtu	---	E
1-02-002-23	Subbituminous Coal Cyclone Furnace	None	1.15×10^{-4}	lb/MMBtu	---	E
1-02-002-24	Subbituminous Coal Spreader Stoker	None	---	lb/MMBtu	2.64×10^{-4} - 5.42×10^{-4}	E
1-02-002-25	Subbituminous Coal Traveling Grate (Overfeed) Stoker	None	---	lb/MMBtu	5.42×10^{-4} - 1.03×10^{-3}	E
1-03-001-02	Anthracite Coal Traveling Grate (Overfeed) Stoker	None	1.90×10^{-4}	lb/ton	ND - 2.40×10^{-4}	E
1-03-002-03	Bituminous Coal Cyclone Furnace	None	1.15×10^{-4}	lb/MMBtu	---	E
1-03-002-05	Bituminous Coal Pulverized Coal: Wet Bottom	None	5.38×10^{-4}	lb/MMBtu	---	E
1-03-002-06	Bituminous Coal Pulverized Coal: Dry Bottom	None	6.84×10^{-4}	lb/MMBtu	---	E
1-03-002-07	Bituminous Coal Overfeed Stoker	None	---	lb/MMBtu	5.42×10^{-4} - 1.03×10^{-3}	E
1-03-002-08	Bituminous Coal Underfeed Stoker	Single Cyclone	2.56×10^{-5}	lb/MMBtu	---	U
1-03-002-09	Bituminous Coal Spreader Stoker	None	---	lb/MMBtu	2.64×10^{-4} - 5.42×10^{-4}	E
1-03-002-21	Subbituminous Coal Pulverized Coal: Wet Bottom	None	5.38×10^{-4}	lb/MMBtu	---	E

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
1-03-002-22	Subbituminous Coal Pulverized Coal: Dry Bottom	None	6.84×10^{-4}	lb/MMBtu	---	E
1-03-002-23	Subbituminous Coal Cyclone Furnace	None	1.15×10^{-4}	lb/MMBtu	---	E
1-03-002-24	Subbituminous Coal Spreader Stoker	None	---	lb/MMBtu	2.64×10^{-4} - 5.42×10^{-4}	E
1-03-002-25	Subbituminous Coal Traveling Grate (Overfeed) Stoker	None	---	lb/MMBtu	5.42×10^{-4} - 1.03×10^{-3}	E
1-01-004-01	Residual Oil Grade 6 Oil: Normal Firing	None	---	lb/MMBtu	1.90×10^{-5} - 1.14×10^{-4}	E
1-01-004-01	Residual Oil Grade 6 Oil: Normal Firing	Flue Gas Recirculation	2.01×10^{-5}	lb/MMBtu	7.90×10^{-6} - 6.54×10^{-5}	U
1-01-004-04	Residual Oil Grade 6 Oil: Tangential Firing	None	---	lb/MMBtu	1.90×10^{-5} - 1.14×10^{-4}	E
1-01-004-05	Residual Oil Grade 5 Oil: Normal Firing	None	6.73×10^{-6}	lb/MMBtu	---	U
1-01-005-01	Distillate Oil Grades 1 and 2 Oil	None	4.20×10^{-6}	lb/MMBtu	---	E
1-02-004-01	Residual Oil Grade 6 Oil	None	---	lb/MMBtu	1.90×10^{-5} - 1.14×10^{-4}	E
1-02-005-01	Distillate Oil Grades 1 and 2 Oil	None	4.20×10^{-6}	lb/MMBtu	---	E
1-05-001-13	Waste Oil: Air Atomized Burner	None	6.00×10^{-2}	lb/1000 Gal	---	D
1-05-001-14	Waste Oil: Vaporizing Burner	None	2.50×10^{-3}	lb/1000 Gal	---	D
1-03-013-02	Waste Oil: Small Boilers	None	1.10×10^{-1}	lb/1000 Gal	---	D
1-05-002-13	Waste Oil: Air Atomized Burner	None	6.00×10^{-2}	lb/1000 Gal	---	D
1-05-002-14	Waste Oil: Vaporizing Burner	None	2.50×10^{-3}	lb/1000 Gal	---	D
1-01-012-01	Solid Waste	ESP	6.87×10^{-5}	lb/ton	3.20×10^{-5} - 1.40×10^{-4}	U

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
5-03-005-01	Hazardous Waste	Absorber/Wet Scrubbers	6.32×10^{-4}	lb/lb	5.62×10^{-4} - 7.53×10^{-4}	U
5-01-001-01	Starved Air: Multiple Chamber	None	6.69×10^{-4}	lb/ton	---	C
5-01-001-01	Starved Air: Multiple Chamber	ESP	1.05×10^{-4}	lb/ton	---	D
5-01-001-03	Refuse Derived Fuel	None	5.94×10^{-3}	lb/ton	---	B
5-01-001-03	Refuse Derived Fuel	ESP	1.34×10^{-4}	lb/ton	---	D
5-01-001-03	Refuse Derived Fuel	Spray Dryer/FF	5.17×10^{-6}	lb/ton	---	A
5-01-001-03	Refuse Derived Fuel	Spray Dryer/ESP	1.08×10^{-5}	lb/ton	---	D
5-01-001-04	Mass Burn Refractory Wall Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-01-001-04	Mass Burn Refractory Wall Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-01-001-04	Mass Burn Refractory Wall Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-01-001-04	Mass Burn Refractory Wall Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-01-001-04	Mass Burn Refractory Wall Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-01-001-05	Mass Burn Waterwall Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-01-001-05	Mass Burn Waterwall Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-01-001-05	Mass Burn Waterwall Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-01-001-05	Mass Burn Waterwall Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-01-001-05	Mass Burn Waterwall Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-01-001-06	Mass Burn Rotary Waterwall Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-01-001-06	Mass Burn Rotary Waterwall Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-01-001-06	Mass Burn Rotary Waterwall Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
5-01-001-06	Mass Burn Rotary Waterwall Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-01-001-06	Mass Burn Rotary Waterwall Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-01-001-07	Modular Excess Air Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-01-001-07	Modular Excess Air Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-01-001-07	Modular Excess Air Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-01-001-07	Modular Excess Air Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-01-001-07	Modular Excess Air Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-03-001-11	Mass Burn Refractory Wall Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-03-001-11	Mass Burn Refractory Wall Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-03-001-11	Mass Burn Refractory Wall Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-03-001-11	Mass Burn Refractory Wall Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-03-001-11	Mass Burn Refractory Wall Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-03-001-12	Mass Burn Waterwall Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-03-001-12	Mass Burn Waterwall Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-03-001-12	Mass Burn Waterwall Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-03-001-12	Mass Burn Waterwall Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-03-001-12	Mass Burn Waterwall Combustor	ESP	2.17×10^{-5}	lb/ton	---	A

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
5-03-001-13	Mass Burn Rotary Waterwall Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-03-001-13	Mass Burn Rotary Waterwall Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-03-001-13	Mass Burn Rotary Waterwall Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-03-001-13	Mass Burn Rotary Waterwall Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-03-001-13	Mass Burn Rotary Waterwall Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-03-001-14	Modular Starved-air Combustor	None	6.69×10^{-4}	lb/ton	---	C
5-03-001-14	Modular Starved-air Combustor	ESP	1.05×10^{-4}	lb/ton	---	D
5-03-001-15	Modular Excess-air Combustor	None	4.37×10^{-3}	lb/ton	---	A
5-03-001-15	Modular Excess-air Combustor	Spray Dryer/FF	4.23×10^{-6}	lb/ton	---	A
5-03-001-15	Modular Excess-air Combustor	Spray Dryer/ESP	1.37×10^{-5}	lb/ton	---	A
5-03-001-15	Modular Excess-air Combustor	Dry Sorbent Injection/FF	1.03×10^{-5}	lb/ton	---	C
5-03-001-15	Modular Excess-air Combustor	ESP	2.17×10^{-5}	lb/ton	---	A
5-01-005-06	Sludge Incinerator	None	6.2×10^{-3}	lb/ton	$3.20 \times 10^{-4} - 5.60 \times 10^{-2}$	U
5-01-005-15	Multiple Hearth Furnace	None	9.40×10^{-3}	lb/ton	---	B
5-01-005-15	Multiple Hearth Furnace	Single Cyclone/Venturi Scrubber	2.00×10^{-4}	lb/ton	---	E
5-01-005-15	Multiple Hearth Furnace	FF	6.00×10^{-6}	lb/ton	---	E
5-01-005-15	Multiple Hearth Furnace	Venturi Scrubber/Impingement Type Wet Scrubber/Afterburner	8.00×10^{-5}	lb/ton	---	E
5-01-005-15	Multiple Hearth Furnace	ESP	2.40×10^{-3}	lb/ton	---	E
5-01-005-15	Multiple Hearth Furnace	Venturi Scrubber	1.00×10^{-4}	lb/ton	---	E

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
5-01-005-15	Multiple Hearth Furnace	Venturi Scrubber/Wet ESP	1.20×10^{-3}	lb/ton	---	E
5-01-005-15	Multiple Hearth Furnace	Venturi Scrubber/Impingement Type Wet Scrubber	1.20×10^{-3}	lb/ton	---	B
5-01-005-15	Multiple Hearth Furnace	Single Cyclone/Venturi Scrubber/Impingement Scrubber	1.70×10^{-3}	lb/ton	---	E
5-01-005-15	Multiple Hearth Furnace	Single Cyclone/Impingement Plate Scrubber	4.10×10^{-3}	lb/ton	2.30×10^{-4} - 2.02×10^{-2}	U
5-01-005-15	Multiple Hearth Furnace	Scrubber	3.00×10^{-3}	lb/ton	---	U
5-01-005-16	Other Incineration/ Sludge: Fluidized Bed	Venturi Scrubber/Impingement Plate Scrubber	1.20×10^{-4}	lb/ton	---	U
5-01-005-16	Other Incineration/ Sludge: Fluidized Bed	None	4.40×10^{-3}	lb/ton	---	E
5-01-005-16	Other Incineration/ Sludge: Fluidized Bed	Single Cyclone/Impingement Tray Scrubber	1.00×10^{-4}	lb/ton	5.60×10^{-4} - 2.40×10^{-4}	U
5-01-005-16	Other Incineration/ Sludge: Fluidized Bed	Low Energy Cyclone/ Impingement Tray Scrubber	6.80×10^{-4}	lb/ton	---	U
5-01-005-16	Other Incineration/ Sludge: Fluidized Bed	Venturi Scrubber/Impingement Type Wet Scrubber	3.00×10^{-5}	lb/ton	---	E
5-01-005-16	Other Incineration/ Sludge: Fluidized Bed	Venturi Scrubber/Impingement Type Wet Scrubber/ESP	1.00×10^{-5}	lb/ton	---	E
5-01-005-05	Pathological/Rotary Kiln	None	3.32×10^{-4}	lb/ton	---	E
5-01-005-05	Pathological/Controlled Air	None	2.42×10^{-4}	lb/ton	---	B
5-01-005-05	Pathological	Wet Scrubber - High Efficiency	3.27×10^{-5}	lb/ton	---	E
5-01-005-05	Pathological	Wet Scrubber - Medium Efficiency/FF	3.27×10^{-5}	lb/ton	---	E
5-01-005-05	Pathological	FF	3.95×10^{-8}	lb/ton	---	E
5-01-005-05	Pathological	Wet Scrubber - Low Efficiency	1.42×10^{-4}	lb/ton	---	E
5-01-005-05	Pathological	Dry Sorbent Injection/ESP	5.01×10^{-5}	lb/ton	---	E
5-01-005-05	Pathological	Dry Sorbent Injection/FF	1.19×10^{-5}	lb/ton	---	E

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
5-01-005-05	Pathological	Dry Sorbent Injection/Carbon Injection/FF	1.46×10^{-5}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological/Rotary Kiln	None	3.32×10^{-4}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological/Controlled Air	None	2.42×10^{-4}	lb/ton	---	B
5-02-005-05	Commercial Incineration - Pathological	None	1.62×10^{-4}	lb/ton	$7.42 \times 10^{-5} - 2.16 \times 10^{-4}$	U
5-02-005-05	Commercial Incineration - Pathological	FF	3.95×10^{-8}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological	Wet Scrubber - High Efficiency	3.27×10^{-5}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological	Wet Scrubber - Medium Efficiency/FF	3.27×10^{-5}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological	Wet Scrubber - Low Efficiency	1.42×10^{-4}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological	Dry Sorbent Injection/ESP	5.01×10^{-5}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological	Dry Sorbent Injection/Carbon Injection/FF	1.46×10^{-5}	lb/ton	---	E
5-02-005-05	Commercial Incineration - Pathological	Dry Sorbent Injection/FF	1.19×10^{-5}	lb/ton	---	E
5-03-002-03	Simulated Open Burning of Chunk Automobile Tires	None	1.00×10^{-1}	lb/1000 ton	---	C
5-03-002-03	Simulated Open Burning of Shredded Automobile Tires	None	4.00×10^{-1}	lb/1000 ton	---	C
3-15-021-01	Crematory Stack	None	3.00×10^{-5}	lb/Body	$< 2.73 \times 10^{-5} - 6.19 \times 10^{-5}$	U
2-01-001-01	Distillate Oil Fired Turbine	None	4.90×10^{-6}	lb/MMBtu	---	E
3-02-007-73	Grain Milling, Rice Drying	None	1.30×10^{-6}	lb/ton	$1.10 \times 10^{-6} - 1.40 \times 10^{-6}$	U

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
3-02-007-74	Grain Milling, Rice Cleaning/Millhouse	None	1.20×10^{-6}	lb/ton	9.95×10^{-7} - 1.26×10^{-6}	U
3-03-010	Entire Process	FF	1.94×10^{-1}	lb/ton	2.80×10^{-2} - 5.80×10^{-1}	U
3-04-005-99	Smelting Furnace	FF	6.20×10^{-4}	lb/ton	---	U
3-04-004-99	Blast Furnace (Afterburner Outlet)	Afterburner	$< 1.50 \times 10^{-1}$	lb/ton	1.10×10^{-1} - 1.80×10^{-1}	U
3-04-004-99	Area Emission Material Storage and Handling	None	1.20×10^{-1}	lb/ton	---	U
3-04-004	Fugitives (Furnace Charging and Tapping)	FF	5.60×10^{-2}	lb/ton	---	U
3-04-004	Blast and Reverberatory Furnaces	FF/Wet Scrubber - Medium Efficiency	2.80×10^{-3}	lb/ton	---	U
3-04-004-03	Blast Furnace	Afterburner/Cyclones/FF	2.90×10^{-4}	lb/ton	---	U
3-04-004-14	Blast Furnace and Kettle Refining	Afterburner/FF/Venturi Scrubber/Demister	3.0×10^{-4}	lb/ton	---	U
3-03-005-24	Primary Copper Smelting AFT MHR + RF/FBR + EF	None	---	lb/ton	4.45 - 6.28	U
3-03-005-15	Converter - Fugitive Emissions	None	---	lb/ton	3.50×10^{-2} - 1.74×10^{-1}	U
3-03-005-14	Reverberatory Furnace - Fugitive Emissions	None	---	lb/ton	7.20×10^{-3} - 1.20×10^{-2}	U
3-03-005-09	Fluidized Bed Roaster	None	---	lb/ton	1.90×10^{-2} - 3.10×10^{-2}	U
3-03-005-02	Multiple Hearth Roaster	None	---	lb/ton	2.90×10^{-1} - 4.60×10^{-1}	U
3-03-005-03	Reverberatory Smelter (After Roaster)	None	---	lb/ton	1.80 - 9.37	U
3-03-005-04	Converter (All Configurations)	None	---	lb/ton	2.00×10^{-4} - 1.40×10^{-3}	U
3-03-005-03	Reverberatory Smelter (After Roaster)	ESP	---	lb/ton	8.00×10^{-2} - 2.60×10^{-1}	U
3-03-005-04	Converter (All Configurations)	ESP	---	lb/ton	2.00×10^{-4} - 7.00×10^{-4}	U

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
3-03-005-04	Converter (All Configurations)	Baghouse	---	lb/ton	7.00×10^{-4} - 1.60×10^{-2}	U
3-03-005-09	Fluidized Bed Roaster	Venturi Scrubber	---	lb/ton	3.00×10^{-4} - 6.00×10^{-4}	U
3-03-005-13	Roasting - Fugitive Emissions	Spray Chamber/Cold ESP	---	lb/ton	4.40×10^{-3} - 1.60×10^{-2}	U
3-03-005-14	Reverberatory Furnace - Fugitive Emissions	Baghouse	---	lb/ton	7.40×10^{-3} - 8.70×10^{-3}	U
3-03-005-24	Primary Copper Smelting AFT MHR+RF/FBR+EF	Spray Chamber/Baghouse	---	lb/ton	4.10×10^{-2} - 8.10×10^{-2}	U
3-04-001-09	Burning/Drying	Venturi Scrubber	4.72×10^{-6}	lb/ton	3.74×10^{-6} - 5.78×10^{-9}	U
3-04-001-09	Burning/Drying	Baghouse	$< 1.26 \times 10^{-6}$	lb/ton	1.13×10^{-6} - 1.54×10^{-6}	U
3-04-001-09	Burning/Drying	Multiple Cyclones	2.12×10^{-5}	lb/ton	1.67×10^{-5} - 2.74×10^{-5}	U
3-03-007-01	Electric Arc Furnace	None	2.64×10^{-2}	lb/MWh	---	U
3-03-007-02	Electric Arc Furnace	None	1.90×10^{-3}	lb/MWh	---	U
3-03-007-02	Electric Arc Furnace	Venturi Scrubber	1.30×10^{-4}	lb/MWh	---	U
1-02-007-99	Process Gas - Landfills	None	4.32×10^{-6}	lb/MMBtu	4.19×10^{-6} - 4.42×10^{-6}	U
3-09-001-98	Fabricated Metal Products: Arc Furnace	Baghouse	5.62×10^{-6}	lb/ton	4.37×10^{-6} - 7.49×10^{-6}	U
3-04-003-01	Iron Foundry - Cupola	None	3.24×10^{-5}	lb/ton	---	U
3-04-003-01	Iron Foundry - Cupola	Baghouse	$< 9.89 \times 10^{-6}$	lb/ton	$< 6.17 \times 10^{-6}$ - 1.72×10^{-5}	U
3-05-002-01	Rotary Dryer: Conventional Plant	FF	6.60×10^{-7}	lb/ton	---	E
3-05-002-01	Rotary Dryer: Conventional Plant	Multiple Cyclone without Fly Ash Reinjection/FF	3.53×10^{-7}	lb/ton	$< 6.33 \times 10^{-8}$ - 9.33×10^{-7}	U
3-05-002-05	Drum Dryer: Hot Asphalt Plants	None	2.50×10^{-7}	lb/ton	2.30×10^{-7} - 2.70×10^{-7}	U
3-05-002-05	Drum Dryer: Hot Asphalt Plants	FF	1.10×10^{-6}	lb/ton	---	D
3-05-035-05	Rotary Dryer: Sand Blasting Grit	Wet Scrubber	2.40×10^{-4}	lb/ton	---	E
3-05-006-06	Dry Process Kiln	ESP	1.27×10^{-4}	lb/ton	---	D

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
3-05-006-06	Dry Process Kiln	Quench Tower/FF	1.22×10^{-5}	lb/ton	---	D
3-05-006-06	Dry Process Kiln	Quench Tower/FF	1.21×10^{-5}	lb/ton	---	D
3-05-006-06	Dry Process Kiln	FF	1.87×10^{-6}	lb/ton	---	D
3-05-006-06	Dry Process Kiln	Multiple Cyclones/FF	1.18×10^{-5}	lb/ton	---	D
3-05-006-06	Dry Process Kiln	FF	1.20×10^{-5}	lb/ton	---	D
3-05-006-06	Dry Process Kiln	ESP	1.30×10^{-5}	lb/ton	---	E
3-05-006-22	Dry Process Preheater Kiln	FF	1.20×10^{-5}	lb/ton	---	D
3-05-006-22	Dry Process Preheater Kiln	ESP	1.30×10^{-5}	lb/ton	---	E
3-05-006-23	Dry Process Preheater/Precalciner Kiln	FF	1.20×10^{-5}	lb/ton	---	D
3-05-006-23	Dry Process Preheater/Precalciner Kiln	ESP	1.30×10^{-5}	lb/ton	---	E
3-05-007-06	Wet Process Kilns	FF	1.20×10^{-5}	lb/ton	---	D
3-05-007-06	Wet Process Kilns	ESP	1.30×10^{-5}	lb/ton	---	E
3-07-001-04	Direct Contact Evaporator Kraft Recovery Furnace	ESP	34	lb/MMton BLS	---	D
3-07-001-10	Nondirect Contact Evaporator Kraft Recovery Furnace	ESP, ESP and Wet Scrubber	15.4	lb/MMton BLS	---	D
3-07-001-05	Smelt Dissolving Tank	Demister	7.0×10^{-1}	lb/MMton BLS	---	D
3-07-001-06	Lime Kiln	None	4.68×10^{-7}	lb/ADTP	---	U
3-07-001-06	Lime Kiln	Scrubber	14.5	lb/MMton BLS	---	D
3-07-002-22	Sulfite Recovery Furnace	None	3.4	lb/MMton RLS	---	D

TABLE A-1. CONTINUED

SCC Number	Emission Source	Control Device	Average Emission Factor	Units	Emission Factor Range	Emission Factor Rating
3-05-014	Glass Manufacture - Regenerative-type Furnace	None	5.00×10^{-1}	lb/ton	---	U
3-10-004-13	Oil and Gas Production, Process Heaters, Crude Oil, Steam Generator	None	9.49×10^{-6}	lb/MMBtu	4.14×10^{-6} - 1.27×10^{-5}	U
3-06-001-01	Petroleum Industry, Pipelines, Oil-Fired Process Heaters	None	4.00×10^{-6}	lb/MMBtu	3.80×10^{-6} - 4.30×10^{-6}	U
3-10-004-02	Oil and Gas Production, Residual Oil-Fired Process Heater	None	2.50×10^{-6}	lb/MMBtu	9.70×10^{-7} - 5.16×10^{-6}	U

TECHNICAL REPORT DATA (PLEASE READ INSTRUCTIONS ON THE REVERSE BEFORE COMPLETING)		
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16. ABSTRACT <p>TO ASSIST GROUPS INTERESTED IN INVENTORYING AIR EMISSIONS OF VARIOUS POTENTIALLY TOXIC SUBSTANCES, THE U.S. ENVIRONMENTAL PROTECTION AGENCY IS PREPARING A SERIES OF DOCUMENTS, SUCH AS THIS, TO COMPILE AVAILABLE INFORMATION ON SOURCES AND EMISSIONS OF THESE SUBSTANCES. THIS DOCUMENT DEALS SPECIFICALLY WITH ARSENIC AND ARSENIC COMPOUNDS. ITS INTENDED AUDIENCE INCLUDES, FEDERAL, STATE, AND LOCAL AIR POLLUTION PERSONNEL AND OTHERS INTERESTED IN LOCATING POTENTIAL EMITTERS OF ARSENIC AND IN MAKING GROSS ESTIMATES OF AIR EMISSIONS THEREFROM.</p> <p>THIS DOCUMENT PRESENTS INFORMATION ON (1) THE TYPES OF SOURCES THAT MAY EMIT ARSENIC; (2) PROCESS VARIATIONS AND RELEASE POINTS FOR THESE SOURCES; AND (3) AVAILABLE EMISSIONS INFORMATION INDICATING THE POTENTIAL FOR ARSENIC RELEASES INTO THE AIR FROM EACH OPERATION.</p>		
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